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OVERTHRUSTING IN ARBUCKLE MOUNTAINS, OKLAHOMA[1]

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ABSTRACT

Until recent years, geologists have looked upon the Arbuckle Mountains of south-central Oklahoma, as a single, unit uplift, formed at one period within Pennsylvanian time, and considerably modified by normal or gravity faulting. The uplift is now shown to be a structural complex composed of two major anticlines—the Hunton-Tishomingo arch and the Arbuckle anticline—with axes trending northwest and southeast, and these folds are shown to have been formed at different periods.

Pre-Atoka (pre-Pottsville) rocks in the Hunton-Tishomingo arch are overlapped by all younger Pennsylvanian beds, indicating the age of the uplift as early Pennsylvanian. In the Arbuckle anticline, pre-Pontotoc (pre-Monongahela) rocks are essentially conformable with all the lower Paleozoic formations, thus indicating the late Pennsylvanian age of that fold.

Evidence is also presented to show that extensive thrust faulting accompanied the late movements, that many of the faults are probably of the low-angle, compression type, that the Arbuckle anticline was thrust a considerable distance northward, overriding the Hunton-Tishomingo arch, and that the latter also experienced considerable thrusting.

INTRODUCTION

The Arbuckle Mountains were named from old Fort Arbuckle, which was located a short distance north of them, in Sec. 25, T. 1 N., R. 1 W., near the present small village of Hoover. The mountains are known, at least by name, to all Mid-Continent geologists, and to many far beyond the confines of that geologic province. Though comparatively small in area, this famous region offers excellent examples of innumerable geologic phenomena, and contains much to intrigue

[1] Read before the Association at the Houston meeting, March 24, 1933. Read in revised form before the 16th International Geological Congress, at Washington, D. C., July, 1933. Manuscript received, December 6, 1933.

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the geologist, whatever be his particular field of specialization. Features of interest to the physiographer, the structural geologist, the stratigrapher, and fossils for the paleontologist, are to be found in profusion.

In addition to being extremely interesting, the area is, happily, unusually accessible, being crossed by one paved highway, and many gravelled roads. Furthermore, secondary roads lead everywhere, and most points of interest may be reached by automobile. The interest and accessibility of the Arbuckle Mountains make them extremely popular among geologists, and many hundreds visit the area each year. These visits have included field conferences of the Oklahoma Geological Survey, The American Association of State Geologists, the Kansas Geological Society, and classes from the State University and other colleges, and vary from individual expeditions to the recent excursion of the Sixteenth International Geological Congress.

The Arbuckles are only a portion of a geologic province which embraces parts of three states, and the strata exposed in the mountains give the key for the interpretation of the depositional and structural conditions of the correlative beds which are known only from well records. An interpretation of the history of the Arbuckles is, therefore, a valuable guide to the interpretation of data revealed by drilling.

Until recent years, geologists have looked upon the Arbuckle Mountains as a single, anticlinal uplift, considerably deformed by normal or gravity faulting, and have believed that all the movement occurred during one short epoch within the Pennsylvanian period. It is the purpose of this paper to present evidence for the conclusion that the region contains two distinct uplifts, formed at different times within the Pennsylvanian: one near the beginning of the period, the other near its close. Evidence is also offered to support the hypothesis that at least the major faults are not of the normal or gravity type, but are probably low-angle, thrust faults, and that overthrusting has played an important part in the orogenic history of the area.

Acknowledgments.—A debt of gratitude is owing to the many colleagues who have so kindly contributed valuable criticism and help, but particular thanks are given to Frank R. Clark, Ira H. Cram, Shepard W. Lowman, H. D. Miser, D. C. Nufer, L. C. Snider, C. W. Tomlinson, W. A. J. M. van der Gracht, Ed. Bloesch, and Charles Ryniker.

LITERATURE ON ARBUCKLE MOUNTAINS

The bibliography of literature on the Arbuckle Mountains contains scores of titles, beginning with Jules Marcou, in 1858. The

ground plan of our present knowledge of the area was laid by the monumental work of Joseph A. Taff, of the United States Geological Survey, in the years 1901–1904, and too high praise can not be given to the contribution of Taff, Ulrich, and their associates. A selected bibliography may be found in the Oklahoma Geological Survey *Bulletin 12*, published in 1928.

PREVIOUS CONCEPTION OF STRUCTURAL HISTORY

Taff[3] pointed out that

> the formations remained in an approximately flat position from the earliest Cambrian to the end of Mississippian time. That there were oscillations of the ocean bed, and probably elevations of the sediments into lowlands at times, is shown by the varying nature of the rocks.

He indicates changes in sediments and important breaks in the entire sequence from Cambrian to the end of Mississippian, as shown by Ulrich's study of fossils, but none of these breaks shows important angular unconformity.

In discussing the Franks conglomerate (p. 34), he states,

> At the close of the Mississippian epoch the Arbuckle region, especially the western part, was uplifted into land and remained so during a large part of Pennsylvanian time. In the western part of the uplift the sediments from the top of the Mississippian well down into the Ordovician, and probably to the Cambrian, were subject to erosion, and lower Carboniferous limestone conglomerates derived from them were spread across their worn edges.

It was apparent to him that this conglomerate thins eastward, and grades into the Wapanucka limestone of the basal Pennsylvanian, and that it changes from complete unconformity on the edges of strata from Ordovician to Mississippian, in the western part, to apparent conformity above the Caney (Mississippian) shale, in the eastern part.

After discussing the post-Mississippian folding in the chapter on structure (pp. 37–38), Taff states

> Faulting on a large scale also occurred, involving the whole Paleozoic section below the top of the Mississippian, besides the pre-Cambrian granite and prophyry. . . . At a still later time, before the close of the Carboniferous, the sediments were again folded and elevated into land. This folding affected the recently formed conglomerates as well as all the rock previously deposited. Faulting occurred also after the deposition of the conglomerate.

The following quotations from the chapter on Geologic Structure in the Tishomingo Folio summarize Taff's conception of the general structure of the Arbuckles:

[3] Joseph A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, Indian Territory and Oklahoma," *U. S. Geol. Survey Prof. Paper 31* (1904), p. 37. Reprinted as *Oklahoma Survey Bull. 12* (1928).

The Arbuckle uplift is composed of a number of folds which together make a broad arch flexed downward upon the sides. The axial parts of the anticlines, wherein are exposed a great thickness of massive Cambro-Silurian (Ordovician) limestone, are generally broadly flexed; while the younger, softer, and thinner rocks of the intervening synclines are crumpled into many small folds, but in no place are they closely pressed or overturned. These synclines are faulted and displaced to an extraordinary degree. . . .

In the Tishomingo quadrangle and elsewhere in the Arbuckle uplift the main faults are approximately parallel with the folds. The larger synclinal folds are generally faulted on both sides as well as within, and the displacements are downward toward the axes, usually without marked shearing or crushing of the strata near the faults. . . . While the faults are generally parallel with the axes of the folds they do not usually follow the strike of the rocks. . . .

The general parallelism of the larger folds and faults would suggest that the common cause of their formation was the action of horizontal forces.

Faults of extensive displacements produced by horizontal forces usually develop from folds which are overturned and finally ruptured, the anticlinal portion being thrust over the synclinal. The plane of such faults would be more or less parallel with the bedding of the overthrust portion. Such conditions do not occur along the faults of this area. The folds are open and never overturned, and the dips of the beds along the faults are usually in the opposite direction from the hade of the theoretical thrust plane.

The general discordance in the strike of the rocks on the opposite sides of the faults, the absence of pronounced shearing or crushing of the strata, even where the displacement is great, the openness of the folding with no indication of dips in the direction of the downthrow along the faults clearly indicate that the faulting, in most cases, at least, is of the normal type or drop faulting.

It is evident from the foregoing that Taff looks upon the Arbuckles as a single, broad geanticline, composed of a number of folds of lesser magnitude, considerably deformed by normal or drop faulting, with little or no thrusting, and that the principal movement occurred at one time, near the beginning of the Pennsylvanian period.

Reeds,[4] like Taff, regards the Arbuckle Mountains as a single unit of uplift, formed at one time, in early Pennsylvanian (p. 42). He does, however, conclude that (p. 68)

they constitute a district of complex folds and not of composite folds as described by Taff. Two sets of folds have been developed which intersect each other almost at right angles.

He recognizes thrusting as the probable mechanics of the movement, and states,

A longitudinal set (of folds), extending N. 70 degrees W. is more prominent, since they were formed by a major thrust acting at right angles to their present extension.

[4] Chester A. Reeds, "A Report on the Geological and Mineral Resources of the Arbuckle Mountains, Oklahoma," *Oklahoma Geol. Survey Bull. 3* (1910), pp. 43 and 68.

He goes on to cite evidence for the existence of minor thrusts which were almost equal to the major one. In his discussion of the thrusts (p. 45), he states,

> As the Arbuckle and Tishomingo anticlines are steeper in their north limbs than in their south ones, it would seem that the major thrust came from the southwest. It is difficult to determine whether the minor thrust was supplied from the southeast or northwest.

Discussing faulting (pp. 47–48), Reeds states:

> One of the greatest adjustments modifying the form of the folds is faulting. From a study of the major faults of the district it has been observed that generally the overhanging side has descended with reference to the other. They should be classified as tension faults rather than compression faults or as usually defined normal faults rather than thrust faults. . . . But the normal faults are not the only kind that are in evidence. In the Mill Creek syncline heave faults are in evidence. . . .

Though recognizing the movements as the result of thrusting or compression, he interprets the faulting as of the normal or tension type.

Attention should be called to one other of Reeds' conceptions. In Plate XVI, "Outline Structural Map of the Arbuckle Mountains" (reproduced here as Figure 1), he indicates that the Arbuckle anticline extends east of Washita River for a distance of nearly 15 miles, in a narrow band of rocks lying south of the Tishomingo anticline. This is important in the present discussion, and will be referred to later.

Reeds summarizes the later history of the Arbuckles under Physiography (p. 68) as follows:

> The mountains have not always remained dormant since the prominent uplift of Pennsylvanian time was followed by times of elevation during the Jura-Trias, Eocene and Pliocene periods. This is attested by records of the Cretaceous base level and the interrupted Miocene and Pleistocene erosion cycles. . . .

Moore[5] regards the Arbuckles as a single uplift, to which the Criner Hills are closely related. He says (p. 35):

> The origin and time of uplift of the Criners is identical with that of the Arbuckles and they may be considered as an essential part of a single orogenic movement.

He calls attention to the fact that the beds of the Pennsylvanian "Glenn formation" of the Ardmore basin

[5] R. C. Moore, "The Relation of Mountain Folding to the Oil and Gas Fields of Southern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (January–February, 1921), pp. 32–48.

. . . are steeply folded and conform in their structure to the folding of the underlying rocks in the Arbuckle Mountains and Criner Hills. It is very evident that the deformation of the Glenn formation was effected at the same time as that of the Arbuckle Mountain area and that the geological date of the orogenic movement was at least post-Glenn.

Moore correlates the "Glenn formation" with the formations northeast of the mountains from the Wapanucka to the Holdenville inclusive, and thus dates the uplift as middle Pennsylvanian, rather than early Pennsylvanian, as Taff and Reeds believe. He discusses the presence of limestone conglomerate (Franks) covering the eroded edges of Glenn as well as older formations, and says (p. 40):

. . . Detailed field studies under the direction of A. W. McCoy have recently shown that the conglomerates may be traced . . . northward . . . into Seminole County where they are found to be identical with the Seminole conglomerate of Taff.

This seemed to confirm the Mid-Pennsylvanian age of the uplift.

McCoy[6] dates the uplift as coming at the end of Lansing time (of the Kansas nomenclature), for on page 566 he says:

. . . there comes a marked break in the character of the sediments throughout east central and northern Oklahoma. It is just previous, or during this time that the Arbuckle Mountains are thought to have been formed as shown by the Seminole conglomerate, which has been traced from the region of Sulphur, Oklahoma . . . into the red, sandy sediments between the Dewey limestone and the Pawhuska limestone of northern Oklahoma,

and previously, on page 546 he says:

To the south the main conglomerate (of the Seminole) has been traced around the north flank of the Arbuckle Mountains within a few miles of Sulphur, Oklahoma. . . . Consequently the Franks conglomerate of the western Arbuckle region must be correlated with the Seminole conglomerate of east central Oklahoma. The conglomerate at Franks, Oklahoma, where the same received its name, can not be traced definitely into any stratigraphic zone, but according to the position of the Wapanucka formation it has probably been erroneously correlated with that particular horizon. . . .

Dake[7] discusses briefly the Ordovician sections of the Wichita, Arbuckle, and Ouachita mountains, and in commenting on the great difference in facies between the latter two, now present within 15 miles of each other, he remarks on page 55:

[6] Alex. W. McCoy, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (September–October, 1921), pp. 541–84.

[7] C. L. Dake, "The Problem of the St. Peter Sandstone," *Bull. School of Mines and Metallurgy* (University of Missouri, Rolla), Vol. 6, No. 1 (August, 1921).

To the writer, the observed conditions suggest an enormous overthrust fault, the displacement measured in scores of miles. . . .

This appears to be the first time that overthrusting was mentioned as a factor in producing any of the Oklahoma mountains, and has since been almost universally accepted as applying to the Ouachitas.

Morgan[8] contributes much to an understanding of the structural history of the Arbuckle Mountains, by differentiating the Pennsylvanian formations exposed in the Stonewall Quadrangle, in the northeastern part of the Arbuckle area. He extends the mapping of the formations established by Taff in the Atoka and Coalgate quadrangles, establishes several new formations included in the section from the highest formations identified by Taff, upward into the basal Permian, and shows that much of the Franks conglomerate, as defined by Taff, is in reality equivalent to various Pennsylvanian formations mapped in the Coalgate Quadrangle.

Taff had found conglomerates at Franks, at Ada, at Sulphur, and around the west end of the mountains, which he interprets as being of the same age, and equivalent to the basal Pennsylvanian Wapanucka limestone. Morgan finds that all these conglomerates are much younger than Wapanucka; that those southeast of Franks are of lower, but not basal, Pennsylvanian; that those west of Franks are equivalent to the younger formations of Taff (Wewoka, Holdenville, and Seminole) and a still younger formation (Francis); that those at Ada are of still younger Pennsylvanian age, and that those at Sulphur are uppermost Pennsylvanian, and should be included with Taff's "Red Beds of very late Pennsylvanian or early Permian age."

Morgan's discussion of the structure of the Arbuckle Mountains is principally concerned with the northern portion, embraced in the Stonewall Quadrangle, and he makes the following general statement:

The structure of the area is complex and is evidently the result of numerous movements that were quite variable both as to type and point of origin.

The following review summarizes Morgan's conception of structural history. Warping and oscillation took place throughout the pre-Pennsylvanian, with increased magnitude during the Devonian and Mississippian, and the establishment of the Arbuckle axis in early Silurian time. Four important movements are postulated in the Pennsylvanian, one near the end of Atoka time, another toward the close of Savanna time, a strong external impulse from the northward thrusting the Ouachita mass late in Wewoka time, and

[8] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. of Geol. Bull. 2* (Norman, 1924).

Near the close of Vamoosa time there was an unusual uplift of the Arbuckle axis that affected all the area embraced in the Stonewall quadrangle. . . .

The present writer's interest in the area began in 1924–1926, while he was in the employ of The Carter Oil Company and stationed at Ada, Sulphur, and Pauls Valley. His proximity to the mountains gave ample opportunity for frequent trips into them, and resulted in increasing interest in the problems of that region. Interest finally focused on the deformational history of the Arbuckle Mountains.

In 1927, he published a paper[9] in which the history of the advances and retreats of Pennsylvanian seas over the Arbuckle area was presented. In this paper the area was considered as being divided into two distinct uplifts (p. 5): the Arbuckle anticline and the Hunton arch, the former the topographic Arbuckle Mountains, in southwestern Murray County; the latter comprising

. . . a northward plunging anticlinal nose with an axis slightly west of north-south, trending through western Pontotoc County, northward into the Seminole area.

The two uplifts were postulated as having been formed at two distinct periods within Pennsylvanian time: the Hunton arch immediately following the deposition of the Wapanucka limestone (p. 12), and the Arbuckle anticline following the Belle City limestone (p. 17). The suggestion was also made that the present relationship of the rocks in the Arbuckle anticline and the Hunton arch is the result of overthrusting (p. 17), the former having overridden the latter.

Powers[10] recognized a period of folding in the Arbuckle region at the end of the Devonian, and two major periods within the Pennsylvanian period. Uplift took place at the end of Wapanucka time in the Criner Hills and the rest of the Wichita-Red River mountain system and in the northeastern part of the Arbuckles; and late Pennsylvanian movements, indicated by the Pontotoc conglomerates, produced folding on the south flank of the mountains. He suggested another period of movement in mid-Pennsylvanian time, contemporaneous with, and related to, the Ouachita overthrust.

Tomlinson[11] presents evidence that indicates an uplift in the Criner Hills in Dornick Hills (early Pennsylvanian) time, contemporaneous with uplifts in other ranges of the Wichita Mountain system

[9] Robert H. Dott, "Pennsylvanian Paleogeography," *Oklahoma Geol. Survey Bull 40-J* (1927); also *Bull. 40*, Vol. I (1928), pp. 51–69.

[10] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 1031–72.

[11] C. W. Tomlinson, "The Pennsylvanian System of the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 20–22, 24.

(pp. 20–22), and suggests a similar contemporaneous uplift north of Mill Creek, in what he calls the northern Arbuckles, saying that in late Pennsylvanian time, about the end of the Hoxbar epoch, intense folding occurred in

> . . . the region now occupied by the Ardmore Basin and the southern and western portions of the Arbuckle Mountains, which throughout earlier Pennsylvanian time had evidently been a subsiding basin . . . (p. 47).

Van der Gracht,[12] in his comprehensive paper on the mountains of the southwest, agrees in general with the last three authors, and also with the main ideas presented in the present writer's paper, previ-

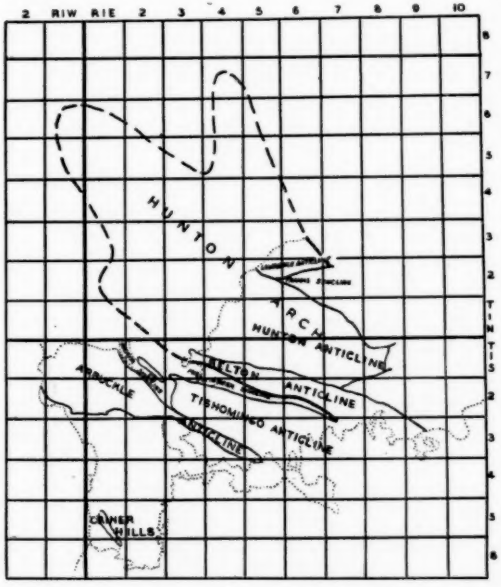

FIG. 1.—Outline structure map of Arbuckle Mountains region, modified after Reeds, *Oklahoma Geol. Survey Bull. 3* (1910), Pl. 16, showing principal structural features, and writer's usage of term "Hunton arch." Broken lines indicate portion buried beneath Pennsylvanian formations. Note extension of Arbuckle anticline southeast, south of Tishomingo anticline.

ously mentioned. To the early Pennsylvanian movement which uplifted the Wichita-Red River system and the Hunton arch, he gives

[12] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (September, 1931), pp. 991–1057. Also *Royal Acad. Sci. Amsterdam*, Sec. 11, Vol. 47, No. 3, pp. 1–170.

the name "Wichita orogeny," and to the later folding, which produced the southern Arbuckles (Arbuckle anticline), the name "Arbuckle orogeny." In the Amsterdam paper he questions the occurrence of true overthrusting in the Arbuckle Mountains.

The foregoing review of previous literature presents the evolution of ideas on Arbuckle structure from that of a single uplift, formed at one period, and modified by normal faulting, to the present conception of two uplifts, formed at different periods, the younger finally overriding the older in a large overthrust, accompanied by extensive thrust faulting.

The writer now wishes to present the evidence which bears on the problem, to analyze in detail the structural features and to restore them to their former shape and position, to advance an explanation of the deformation which the area has suffered, and to point out specific field evidence in its support.

PHYSIOGRAPHY

To all geologists, the term "Arbuckle Mountains" means the entire area in which the lower Paleozoic rocks crop out, and this area is roughly triangular, with the apex at Ada, one angle at Pooleville, and the other at Boggy Depot (Fig. 2).

Locally, and topographically, the term "Arbuckle Mountains" refers only to the high range of hills between Davis and Ardmore, crossed by United States Highway 77, which is so designated on the Ardmore topographic sheet of the United States Geological Survey. These hills are the surface expression of a large anticline, the crest of which has been eroded into a broad, slightly dissected plateau, from which rise two prominent peaks of pre-Cambrian porphyry, known as the "timbered hills," which attain an elevation of 700 feet above the valley of Washita River and 1,400 feet above sea-level. The entire range is composed of a great sequence of rocks which ranges in age from pre-Cambrian to late Pennsylvanian.

A similar succession of rocks occurs, in a much broader plateau, on the east, and though this area contains structural features of mountain proportions, and the surface is locally rugged, the elevations scarcely justify the name "mountains."

The application of the term "Arbuckle Mountains" to the entire area of lower Paleozoic outcrops is too deeply entrenched in geologic usage for it to be used, at this time, in a restricted sense; but it seems important to distinguish between the two physiographic provinces, for they are likewise different geologically. They have different histories, and they were folded at different times, though they are mu-

tually complicated in their present expression. In the following discussion, "Arbuckle anticline" will be used to distinguish the topographic Arbuckle Mountains.

STRATIGRAPHY

Table I gives a generalized section of rocks exposed in the Arbuckle area, and the correlations between the Hunton arch area and the Criner-Ardmore-Arbuckle area, with an indication of standard equivalents. These correlations are taken mainly from Tomlinson,[13] with some modifications by van der Gracht.[14]

The stratigraphy of the region has been well described by previous writers, and the reader is referred to Taff, Ulrich, Reeds, Morgan, Tomlinson, and Decker for the details of the section. It suffices in this connection to state that the pre-Pennsylvanian rocks are predominantly limestone, with minor amounts of sandstone and shale, whereas the Pennsylvanian sediments of the entire region are principally shale, sandstone, and locally, coarse conglomerate, with only minor amounts of limestone.

MAJOR STRUCTURAL FEATURES

The regional structure of the Arbuckle Mountains is a series of parallel folds and faults, trending northwest and southeast, with the Hunton arch and Tishomingo anticline on the north, and the Arbuckle anticline on the south side of the area. The discussion in this paper is confined to the major features, for they hold the key to Arbuckle history, and are important to an understanding of the regional subsurface geology of the part of Oklahoma in which are located the producing oil fields. The reader who may be interested in the details of the numerous minor features is referred to the writings of Taff and Reeds.

The list of major features, from north to south, is as follows: Hunton arch, Mill Creek syncline, Tishomingo anticline, Washita syncline, Arbuckle anticline, Ardmore basin, and Criner Hills (Fig. 1).

South of Ada is a plunging fold which has been variously named, and which has several minor features imposed upon it, each with its own name. This is the exposed part of the Hunton arch described by the writer in 1927.

The writer's conception of the Hunton arch has changed somewhat

[13] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929); also "Oil and Gas Geology of Carter County," *ibid., Bull. 40*, Vol. II (1930), pp. 239–311.

[14] Personal communication.

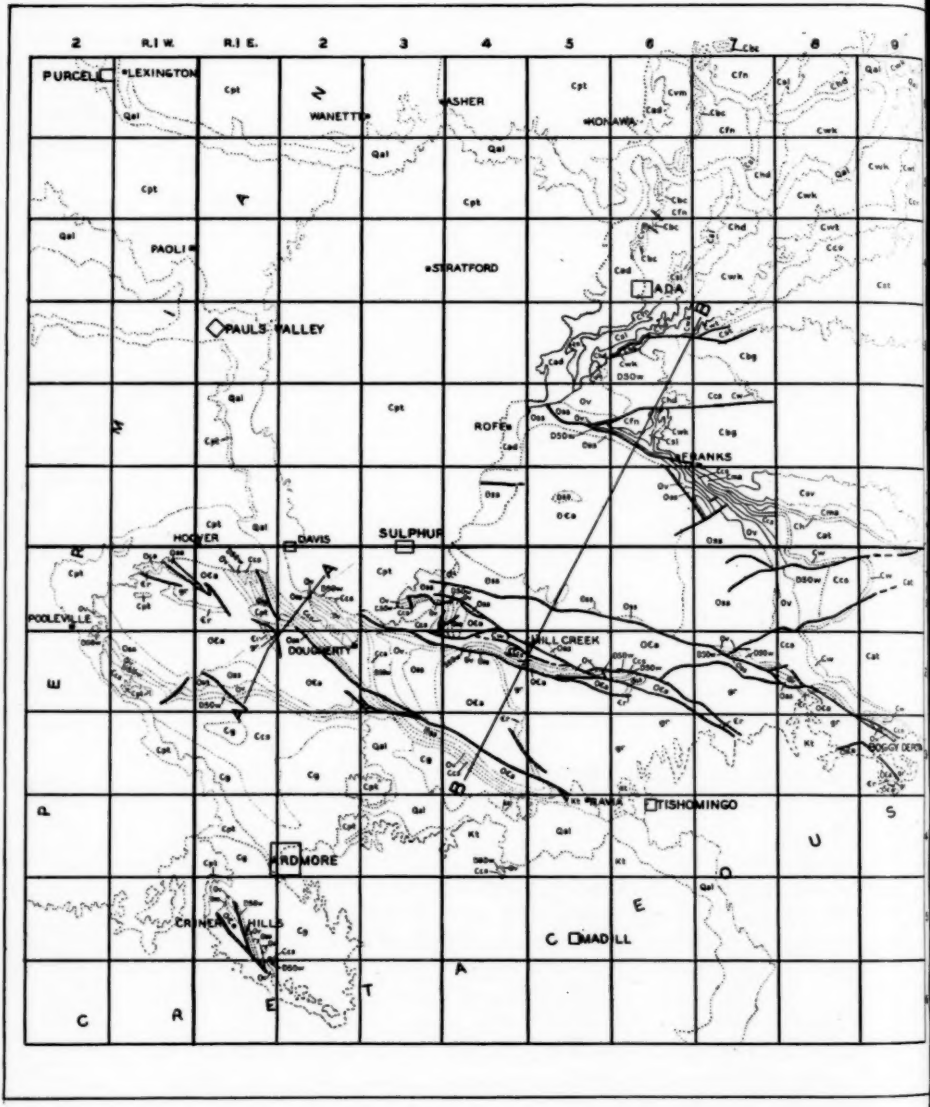

FIG. 2.—Areal geology of south-central Oklahoma, after Miser, "Geologic Map of Oklahoma," *U. S. Geol. Surv.* (1926), corrected in detail from Decker, *et al.*, *Oklahoma Geol. Survey Bull. 55* (1931). Lines *AA* and *BB* refer to loca tions of sections shown in Figure 11. See Table I for key to formations.

TABLE I*

ROCKS EXPOSED IN ARBUCKLE MOUNTAINS AND VICINITY

Standard Equivalents	*Ardmore Basin, Criner Hills and Arbuckle Anticline*		*Map Symbol*	*Hunton Arch Area*		*Map Symbol*
Monongahela	Pontotoc		(Cpt)	Pontotoc		Cpt
	Unconformity					
Conemaugh	Hoxbar	4,000		Ada		Cad
				Vamoosa		Cpo
				Belle City	1,290	Cbc
				Francis		Cfn
				Seminole		Csl
PENNSYLVANIAN Allegheny	Deese	6,000–7,000	(Cg)	Holdenville		Chd
				Wewoka		Cwk
				Wetumka		Cwt
				Calvin	2,100	Ccv
				Senora, Stuart, Thurman		Cst
				Boggy		Cbg
	?					
	Dornick Hills	2,000		Savanna		Csv
				McAlester	1,950	Cma
				Hartshorne		Chs
Pottsville	Bostwick			Atoka		Ca
	Unconformity			*Unconformity*		
Bendian	Otterville, Jolliff			Wapanucka		Cw
	Springer			Upper Caney		
Mississippian	Caney, Sycamore, Woodford		(Ccs)	Lower Caney, Welden, Woodford		Ccs
Devonian	Upper Hunton		(DSOw)	Upper Hunton		DSOw
Silurian	Lower Hunton			Lower Hunton		
Ordovician	Sylvan			Sylvan		
	Viola		(Ov)	Viola		Ov
	Simpson		(Oss)	Simpson		Oss
Cambro-Ordovician	Arbuckle		(Oϵa)	Arbuckle		Oϵa
Cambrian	Reagan		(ϵr)	Reagan		ϵr
Pre-Cambrian	Colbert porphyry		(gp)	Tishomingo granite		gr

* Only major unconformities shown.

Names of Pennsylvanian formations in Hunton arch column arranged to indicate overlap.

Correlations between Hunton arch and Ardmore basin primarily after Tomlinson.

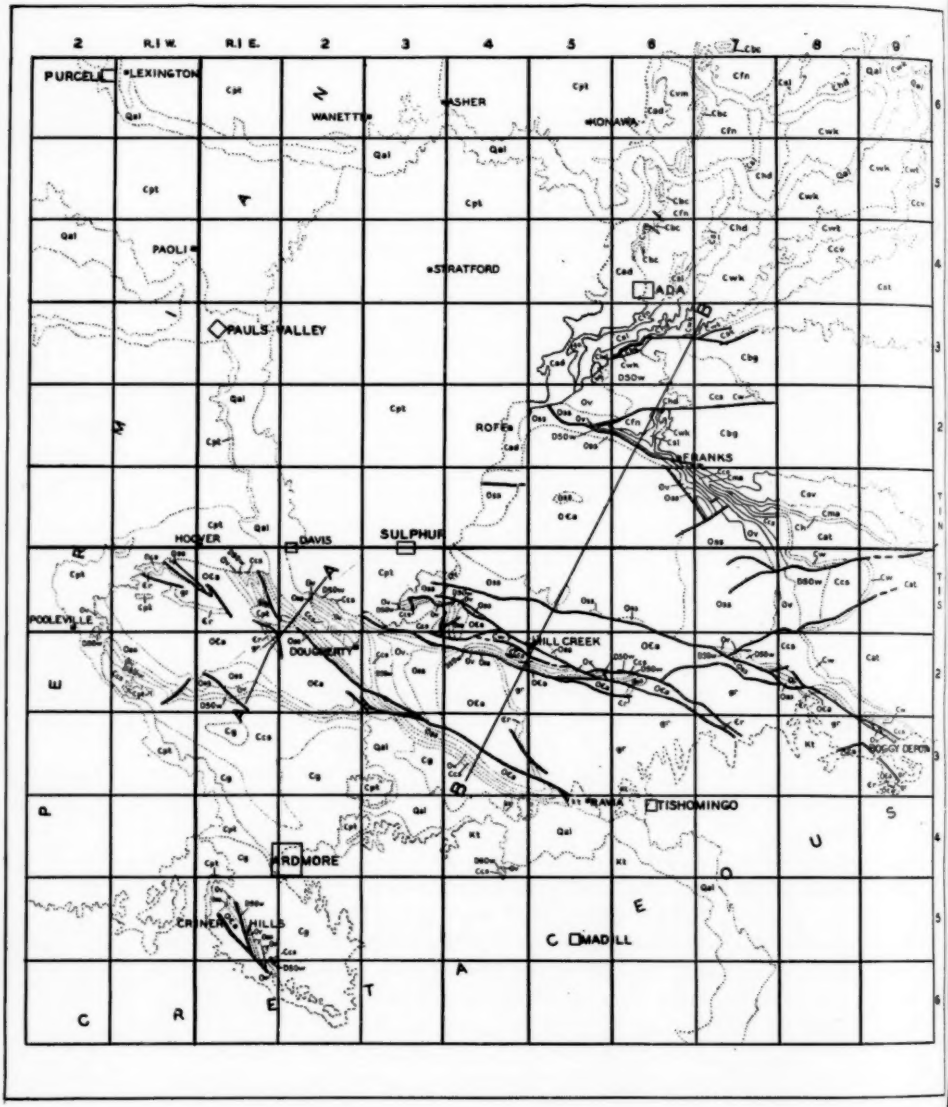

FIG. 2.—Areal geology of south-central Oklahoma, after Miser, "Geologic Map of Oklahoma," *U. S. Geol. Survey* (1926), corrected in detail from Decker, *et al.*, *Oklahoma Geol. Survey Bull. 55* (1931). Lines *AA* and *BB* refer to locations of sections shown in Figure 11. See Table I for key to formations.

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Monongahela	Pontotoc	(Cpt)	Pontotoc		Cpt
	Unconformity				
Conemaugh	Hoxbar 4,000		Ada		Cad
			Vamoosa		Cpo
			Belle City	1,290	Cbc
			Francis		Cfn
			Seminole		Csl
Allegheny	Deese 6,000–7,000	(Cg)	Holdenville		Chd
			Wewoka		Cwk
			Wetumka		Cwt
			Calvin	2,100	Ccv
			Senora, Stuart, Thurman		Cst
			Boggy		Cbg
	?				
	Dornick Hills 2,000		Savanna		Csv
			McAlester	1,950	Cma
			Hartshorne		Chs
Pottsville	Bostwick		Atoka		Ca
	Unconformity		*Unconformity*		
Bendian	Otterville, Jolliff		Wapanucka		Cw
	Springer		Upper Caney		
Mississippian	Caney, Sycamore, Woodford	(Ccs)	Lower Caney, Welden, Woodford		Ccs
Devonian	Upper Hunton	(DSOw)	Upper Hunton		DSOw
Silurian	Lower Hunton		Lower Hunton		
Ordovician	Sylvan		Sylvan		
	Viola	(Ov)	Viola		Ov
	Simpson	(Oss)	Simpson		Oss
Cambro-Ordovician	Arbuckle	(Oϵa)	Arbuckle		Oϵa
Cambrian	Reagan	(ϵr)	Reagan		ϵr
Pre-Cambrian	Colbert porphyry	(gp)	Tishomingo granite		gr

* Only major unconformities shown.

Names of Pennsylvanian formations in Hunton arch column arranged to indicate overlap.

Correlations between Hunton arch and Ardmore basin primarily after Tomlinson.

in the intervening time, and a few words of explanation are pertinent at this time. As pointed out at that time, Taff[15] first gave the name "Hunton anticline" to an eastward plunging fault block occurring in the northwest corner of the Atoka Quadrangle. Later, he expanded the term[16] to include the uplifted area on the west, which lay between his Belton anticline and the syncline which Reeds later called the Franks syncline, and Morgan called the Franks graben. Taff's Hunton anticline trended northwest and southeast.

The writer evidently misinterpreted Taff's description in believing that he also included the later-named Lawrence anticline or uplift as part of the Hunton anticline. The distribution of formations in the Lawrence uplift and Hunton anticline, particularly that of the Simpson group, as shown by the areal map of the region, suggested rather strikingly that together these features make up a northward plunging anticline.

Morgan[17] showed a subsurface nose mapped on top of the Hunton limestone trending northwestward from the Lawrence uplift, and drilling during 1925 and 1926 had given additional datum points on the Hunton, which indicated that this feature continued northward into the Seminole district, in Pottawatomie and Seminole counties. This was mapped by the writer in another paper.[18]

During the drilling which led to the discovery of the Seminole pool, the existence of a large, broad arch or structural ridge became more and more apparent, and it was finally dubbed the "Hunton ridge" by writers in trade journals and newspapers, the name being derived from the formation upon which mapping was done. Through the writer's misconception of Taff's "Hunton anticline" it and the "Hunton ridge" of the trade journals seemed to be the same feature, and therefore, the term "Hunton arch" was applied. "Arch" was used because the term "ridge" had the objection of suggesting a topographic rather than a structural feature.

After the discovery of the Seminole pool, numerous wells were drilled, samples from which have revealed many interesting data, particularly as to the relationship of the Pennsylvanian formations to the pre-Pennsylvanian surface. These data from samples have contributed much toward an understanding of Arbuckle history, and

[15] Robert H. Dott, *Oklahoma Geol. Survey Bull. 40-J* (1927), p. 6.

[16] Joseph A. Taff, *U. S. Geol. Survey Prof. Paper 31* (1904), p. 39.

[17] George D. Morgan, *op. cit.*, Pl. VII.

[18] Robert H. Dott, "Geology of Garvin County," *Oklahoma Geol. Survey Bull. 40-K* (1927), Fig. 3, p. 28; also *Bull. 40*, Vol. II (1930), Fig. 20, p. 140.

have modified, to some extent, the original conception of the "Hunton arch."

It is now evident that the major feature trends northwest and southeast, and includes Taff's Belton anticline, Hunton anticline, and the Lawrence uplift, and extends northwestward under the overlapping Pennsylvanian beds, at least to the vicinity of Pauls Valley; and that the buried part of the writer's "Hunton arch" of 1927 is a spur—an important one, to be sure—off the main uplift. In the present paper, the term Hunton arch is to include Taff's Belton and Hunton anticlines, Reeds' and Morgan's Lawrence anticline or uplift, the same authors' Franks syncline or graben, and the writer's "Hunton arch" of 1927.

Van der Gracht[19] has a somewhat different conception of the Hunton arch, regarding it as a north-south feature, which may have included the Criner Hills, and may even have connected with the Bend arch of Texas. He states (p. 996):

> Another ancient feature, with the same general trend [north-south] and almost certainly originating in the pre-Cambrian floor, is the Hunton arch (or axis). It evidently extends through and beyond the Arbuckle uplift. This ancient positive element must be considered as antedating the geosyncline from which the Wichita complex of mountains originated. It probably caused the present Arbuckle Mountains and the Criner Hills south of them to stand out as uplifts exposing the old mountain structure.

In a letter to the writer, dated May 7, 1933, he referred to magnetic and gravimetric observations which, in his opinion, confirm the presence of a north-south axis, to a certain extent. Some of these geophysical data have recently been published by Van Weelden.[20]

South of the Hunton arch as here outlined, lies a deep, narrow, faulted syncline, the Mill Creek syncline, and south of this another important uplift, the Tishomingo anticline.

In the "Geology of Garvin County" and "Pennsylvanian Paleogeography"[21] appear several statements which reflect the opinion then held by the writer to the effect that the Mill Creek syncline is the eastern extension of the Anadarko basin, which lies in Grady, Caddo, Washita, and Beckham counties.

Although the synclinal area in southern Garvin County is in alignment with the Mill Creek syncline and is not unrelated to the

[19] W. A. J. M. van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (September, 1931), p. 996.

[20] A. Van Weelden, "Regional Tectonical Features of the Wichita-Arbuckle Mountain Region," *The Oil Weekly* (Houston, September 11, 1933), pp. 27–30.

[21] Robert H. Dott, *Oklahoma Geol. Survey Bull. 40.*

Anadarko basin, the major relationship now appears to be between the Anadarko basin and the Ardmore basin, in Carter and Stephens counties, the two together forming a large depression in front of the Wichita mountain system. The Mill Creek syncline is simply a local feature of the Hunton-Tishomingo uplift.

The Tishomingo anticline was described by Taff, and consists of a broad anticline, faulted on both flanks. It and the Hunton arch are thought by the writer to have been originally united in one large uplift.

Southwest from the Tishomingo anticline the rocks dip into a sharp, deep syncline occupied by Washita River, and called the Washita syncline by Taff, and rise again to form the Arbuckle anticline, which is practically co-extensive with the topographic Arbuckle Mountains, already described.

South of the Arbuckle anticline lies the exceedingly deep Ardmore basin, and south of this lower Paleozoic rocks again crop out in the Criner Hills. These are related to the Arbuckle Mountains, and must be considered in connection with the structural history of the latter.

PERIODS OF FOLDING

PRE-PENNSYLVANIAN WARPING

Ample evidence is available to indicate that the whole region underwent gentle warping or oscillation at different times in the early Paleozoic. Ulrich[22] called attention to several breaks in the Arbuckle limestone, Simpson group, and elsewhere in the lower Paleozoic section which indicate such warping.

Decker[23] described three large hiatuses within the Simpson group in the Hunton arch area, where only three formations are present, as compared with five in the rest of the Arbuckle region. Decker also described another important, local unconformity between the Simpson and the Viola limestone.[24]

Another important break may be seen at the base of the Mississippian south of the Tishomingo anticline, where rocks belonging to the Hunton terrane (Siluro-Devonian) are locally absent, and the Woodford shale rests on the Ordovician Sylvan shale.

[22] E. O. Ulrich, Discussion at 16th International Geological Congress, Washington, D. C., 1933.

[23] Charles E. Decker and Clifford A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (1931), p. 16, and map.

[24] Charles E. Decker, "The Viola Limestone, Primarily of Arbuckle and Wichita Mountain Regions, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 1405–36.

These few examples indicate the nature of the pre-Pennsylvanian movements in the Arbuckles. No angularity, and no important conglomerates mark these unconformities, and they seem to be the result of non-deposition and minor erosion following slight warpings, rather than important mountain-building movements.

PENNSYLVANIAN FOLDING

The present attitude of the rocks was produced by two important periods of folding which took place in Pennsylvanian time. The Hunton-Tishomingo fold was uplifted in early Pennsylvanian time, and the Arbuckle anticline in late Pennsylvanian time, testimony to which is borne by the Pennsylvanian rocks themselves.

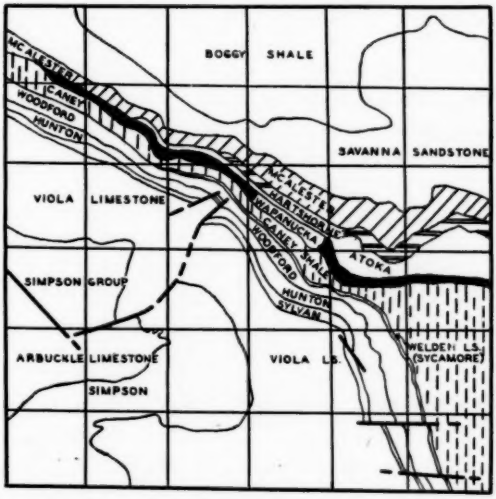


FIG. 3.—Areal geology of T. 1 N., R. 7 E., Pontotoc County, on east side of Hunton arch, showing unconformity and overlap by Lower Pennsylvanian formations. (After George D. Morgan.) McAlester shale may be seen to overlap underlying Hartshorne sandstone, Atoka formation, and Wapanucka limestone, finally resting on Caney shale. Distribution of Atoka and Hartshorne is interpreted as being due to offlap. This is part of widespread unconformity, known through subsurface evidence, in Mid-Continent oil fields, and represents smallest stratigraphic break to be found anywhere in region. It marks uplift of Hunton arch, and places major movement as post-Wapanucka, possibly pre-Atoka, and certainly pre-McAlester.

Early Pennsylvanian fold (Hunton-Tishomingo uplift).—Morgan[25] has shown that beds of Middle Pennsylvanian age overlap one another, and also overlap beds of the underlying lower Paleozoic.

[25] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2* (1924); also *idem*, "The Boggy Overlap," *ibid., Cir. 2* (1924).

Though interrupted at various times, this overlap was progressive from Boggy time, through the Pontotoc (Fig. 2).

In the vicinity of Ada, the Boggy shale overlaps the north end of the Hunton arch, and in that general vicinity lies in contact with all formations from the Wapanucka limestone down to the Viola limestone. In the Franks graben, the Wewoka formation lies on the Boggy shale, and just south of Ada, the Holdenville formation overlaps the Wewoka, and a short distance farther south is found to be in contact with the Boggy shale and the Woodford shale.

The overlying Seminole formation shows a progressive overlap, resting on Viola in the vicinity of Lawrence, and farther south, the Ada formation overlaps the Francis formation, until finally, between Roff and Hickory, the Ada is found in contact with the Arbuckle limestone. All these formations are conglomeratic at their southern margins.

Well samples indicate that the same condition prevails in the subsurface, from the mountains northward, as shown by Figure 4-A. Obviously the area was uplifted before Boggy time.

There is still more evidence to place the time of the uplift as pre-Boggy. Morgan shows that the McAlester overlaps successively the Hartshorne, Atoka, and Wapanucka formations, across T. 1 N., R. 7 E., and finally rests on the Caney shale (Fig. 3).

In discussing the Franks conglomerate, Morgan states:[26]

> The beds in the type area were followed eastward and in that direction were found to be traceable, not into the Wapanucka limestone as reported by Taff, but into the McAlester, Savanna, and Boggy formations. The Wapanucka was found to emerge from beneath the conglomerates at a point about two miles southeast of the town of Franks.

This situation places the uplift as pre-McAlester, and apparently, post-Wapanucka.

Further evidence is worthy of consideration in this connection. The great change in lithology between the Wapanucka shales and limestone, and the coarse, massive sands in the basal part of the overlying Atoka formation indicates a decided change in topography at that time. The great thickness of the Atoka and succeeding formations indicates the initial development of a depositional basin east of the Hunton arch at the beginning of Atoka time. These facts seem to show that the uplift received its greatest impetus in early Atoka time.

Wallis[27] observed unconformities at the bottom, top, and within

[26] *Idem*, "Geology of the Stonewall Quadrangle, Oklahoma," p. 121.

[27] B. F. Wallis, "The Geology and Economic Value of the Wapanucka Limestone of Oklahoma," *Oklahoma Geol. Survey Bull. 23* (1915).

the Wapanucka. Near Bromide, he found pebbles of oölite which he thought might have come from the Hunton limestone. This suggests that the uplift may have started in Wapanucka time. In any event, the proof is rather conclusive that the Hunton arch was uplifted in early Pennsylvanian time.

So far as the part of the Arbuckle uplift included in the Stonewall, Tishomingo, and Atoka quadrangles, is concerned, Taff was correct in assigning the age of folding as "near the beginning of the Pennsylvanian epoch."

This period of early Pennsylvanian uplift is probably the most important in the entire Mid-Continent region, for such important oil producing structures as Oklahoma City, Garber, Cushing, and Eldorado were built at this time. The same period saw the uplift of important areas in Kansas, and of the Bend arch in Texas, and the effects may have reached far beyond the Mid-Continent province.

Of the same age, and more intimately related to the Hunton arch, are the folds which go to make up the Wichita-Red River mountains, and include the Criner Hills, Healdton Hills, Wichita Mountains, Amarillo buried mountains, and the Red River uplift (Fig. 8). These have been well described by Powers[28] and van der Gracht.[29]

So important is this period of uplift, that Moore[30] proposes to draw the boundary between the Mississippian and the Pennsylvanian systems at the top of the Wapanucka-Bendian-Morrow, rather than at the base, as is now done.

Late Pennsylvanian fold (*Arbuckle anticline*).—The correlation chart shown in Table I indicates that the Pennsylvanian formations present in the vicinity of Ada have much thicker equivalents in the vicinity of Ardmore. The members near Ada decrease rapidly in thickness from east to west, and from north to south, and, as has already been shown, are characteristically conglomeratic and definitely overlapping.

The Jolliff and Otterville members of the Dornick Hills formation of the Ardmore basin contain minor amounts of conglomerate, but the overlying Bostwick member is a massive limestone conglomerate in the vicinity of the Criner Hills.[31] Though less conspicuous, some

[28] Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928).

[29] W. A. J. M. van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931).

[30] R. C. Moore, address before the 16th International Geological Congress, Washington, 1933.

[31] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 29–30.

conglomerates have been noted at this horizon, on the north, on the south flank of the Arbuckle anticline.[32]

The Otterville is correlated with the Wapanucka, and the overlying Bostwick with the basal Atoka, giving evidence that the Criner Hills were uplifted at about the same time as the Hunton arch. The Criner Hills are related to the "Wichita uplift" of Powers[33] and were involved in the "Wichita orogeny" of van der Gracht.[34]

Some conglomerates also occur in the succeeding Deese and Hoxbar formations, but most of these occur south and east of Ardmore, and Tomlinson[35] suggests that they were derived from some area or areas farther south and east. There is little striking evidence in the sedimentation to show that the Arbuckle anticline was a land mass during these periods.

The structural work of Taff, Reeds, Goldston, and Tomlinson shows rather definitely their belief in the structural conformity, in the Arbuckle anticline, of the Pennsylvanian beds with the underlying lower Paleozoic formations. In this connection, Tomlinson states (p. 47–48):

> . . . the region now occupied by the Ardmore Basin and the southern and western parts of the Arbuckle Mountains . . . throughout earlier Pennsylvanian [Hoxbar and before] had evidently been a subsiding basin of sedimentation, or geosyncline. . . . No angular unconformity interrupts the essential parallelism of strata from the upper Cambrian Reagan sandstone, to the top of the upper Pennsylvanian Hoxbar.

That last statement requires some modification, for the writer is informed by workers in the area, including Tomlinson, that evidence has been found, in well cuttings, to indicate breaks of considerable magnitude within the Pennsylvanian. Ware[36] called attention to evidence of angular unconformities within the Pennsylvanian, in the Tatums pool, located a few miles southwest of the exposed southwest end of the Arbuckle anticline.

Nufer[37] confirmed the evidence of unconformities in the Tatums pool, and mentioned other, similar indications in dry holes scattered along the north side of the Ardmore basin. In the greatest of the unconformities noted in well cuttings, beds belonging to the upper part of the Deese formation were found to rest on beds of middle

[32] F. W. Floyd, personal communication.

[33] Sidney Powers, *op. cit.*

[34] Van der Gracht, *op. cit.*

[35] C. W. Tomlinson, *op. cit.*, pp. 35, 42–43.

[36] John M. Ware, personal communication.

[37] D. C. Nufer, personal communication.

Springer age. Unconformities of such magnitude indicate that the area of the Arbuckle anticline was subjected to some uplift during lower and middle Pennsylvanian time, though, as will be pointed out below, the major movements occurred much later.

The essential fact remains, however, that no great unconformities are found in the Arbuckle anticline, such as are found in the Hunton

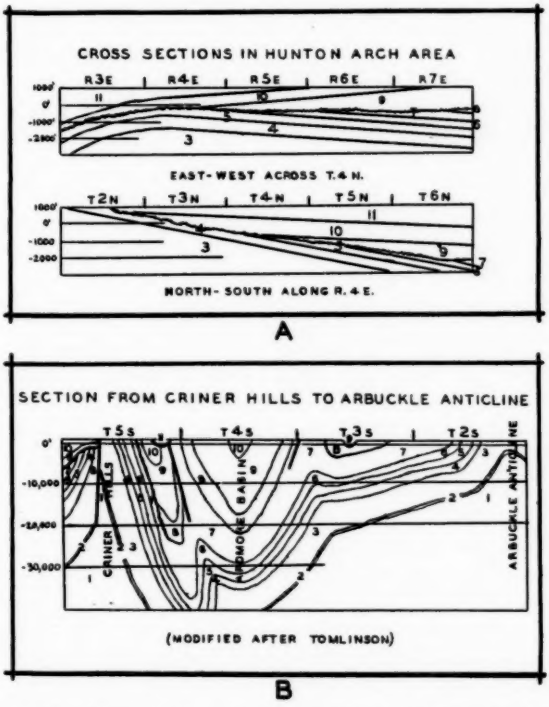


FIG. 4.—Sketch cross sections showing unconformity and overlap of formations above Wapanucka limestone in Hunton arch area, and conformability of equivalent beds in Arbuckle anticline-Ardmore basin area. Legend: *1*—granite; *2*—Reagan sandstone; *3*—Arbuckle limestone; *4*—Simpson group; *5*—Viola limestone; *6*—Sylvan shale and Hunton terrane; *7*—Woodford, Caney and Springer formations; *8*—Dornick Hills-Wapanucka formations; *9*—Deese-Atoka to Holdenville, inclusive; *10*—Hoxbar-Seminole to Ada, inclusive; *11*—Pontotoc formation.

arch; Pennsylvanian beds are not found in contact with lower Paleozoic formations. When the overlapping nature of the Pennsylvanian in the Hunton arch, and the lack of great unconformability of equivalent strata in the Arbuckle anticline (Fig. 4) are remembered, it is quite

evident that there are two folds, or systems of folds, one of early, the other of late Pennsylvanian age. These two diverse Pennsylvanian sections, in such close proximity, gave rise to the writer's original suggestion of overthrusting, made in 1927.[38]

It may be remarked that the conception of the early Pennsylvanian Hunton-Tishomingo uplift, separating the McAlester Coal basin, in Coal, Hughes, Pittsburg, and adjacent counties, from the Ardmore-Arbuckle basin, of Murray and Carter counties, would explain the inability of geologists to definitely correlate the rocks in the two basins. The correlation of the Wapanucka and Otterville limestones, and all older formations seems to be fairly well accepted, but only the most general suggestions are made as to the equivalence of beds between there and the Pontotoc. To be sure, an area 30 miles wide, between the two outcrops, is covered by Cretaceous beds, but the similarity of the sequence within the basins, throughout areas of much greater extent, indicates two different sections of rocks, which were deposited in two distinct basins, separated by an early Pennsylvanian uplift.

ANALYSIS OF FOLDS

This, in brief, is the broad view of the Arbuckle Mountains structural history—two folds, formed at different times within the Pennsylvanian epoch. The folds are mutually complicated in their present expression. They have been squeezed together, one having overridden the other, and in the process, the original forms have been distorted to the point that they are scarcely to be recognized.

It is now the purpose of the writer to disjoint this intricate structural pattern, to isolate the elements of each fold, and to present a synthetic picture of the area at some time before the final movements.

Before any conclusions may be drawn as to the former appearance of these folds, it is necessary to decide which of the present features are related to each other, and which are distinct. The Hunton arch has been sliced into a series of fault blocks, and certain of the relationships are based mainly on inference.

Hunton arch elements.—Wells drilled in the vicinity of Pauls Valley show that beds varying in age from Wewoka to Francis overlap the Viola limestone and associated beds in that region. Morgan has shown that pre-Pontotoc Pennsylvanian beds overlap lower Paleozoic formations as far south as Roff, and in the upper end of the Franks graben.

[38] Robert H. Dott, *Oklahoma Geol. Survey Bull. 40-J* (1927), p. 17; *ibid., Bull. 40*, Vol. I (1928), p. 63.

Tomlinson[39] refers to a bed of conglomerate which occurs near the town of Mill Creek, and states:

> It consists chiefly of limestone pebbles in a limestone matrix, and lies a short distance above a fossiliferous, partly oölitic limestone, which is tentatively correlated with the Otterville and Wapanucka limestones. The conglomerate therefore occupies the relative position of the very member of the Ardmore Basin Pennsylvanian which it most closely resembles—the Bostwick member of the Dornick Hills formation, which carries coarse limestone conglomerates near the Criner Hills. It is quite different from the coarser Pontotoc conglomerates near Sulphur . . . it at least suggests an early Pennsylvanian uplift in that vicinity, originating at the same time as the Criner Hills.

As Tomlinson points out, the relationships of this occurrence at Mill Creek are complicated by faulting, yet the evidence is suggestive

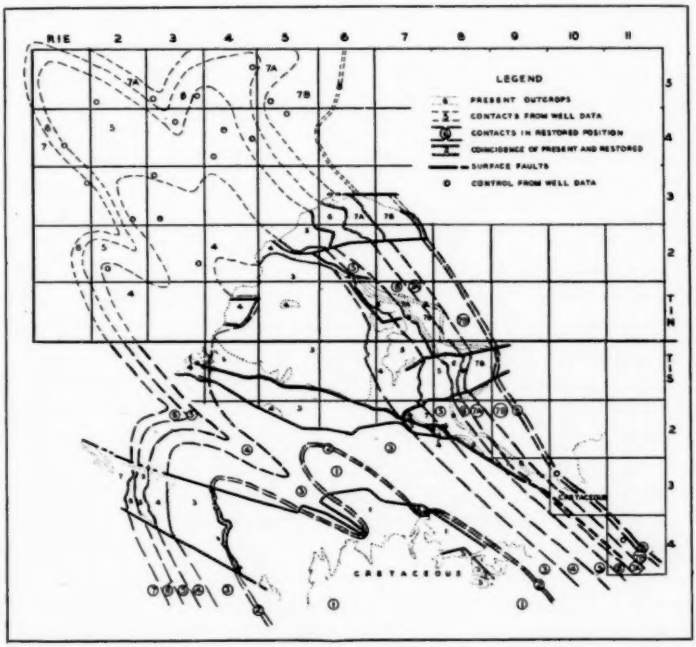


FIG. 5.—Hypothetical restoration of Hunton-Tishomingo uplift in Pennsylvanian time, prior to final overthrusts, suggesting their original unity in one large fold. Key to formations: *1*—granite; *2*—Reagan sandstone; *3*—Arbuckle limestone; *4*—Simpson group; *5*—Viola limestone; *6*—Hunton-Sylvan; *7*—Caney-Woodford (*7 A*—Woodford shale; *7 B*—Caney shale); *8*—Wapanucka limestone.

[39] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), p. 24.

of an early Pennsylvanian uplift in that vicinity, and seems sufficient to identify the area north of Mill Creek as part of the early Pennsylvanian Hunton arch.

The present position of the Tishomingo anticline and the Hunton arch seem to suggest that they were originally part of the same fold. The hypothetical restoration shown in Figure 5 indicates the plausibility of such a relationship.

Tomlinson estimates a crustal shortening of 16 miles, in the Ardmore basin, the result of post-Hoxbar forces which must also have had their effects in deforming the Hunton-Tishomingo fold. Figure 5 was prepared by withdrawing the Tishomingo anticline toward the southwest, in a direction normal to the present trend of the folds and faults, on the assumption that it was thrust to its present position in late Pennsylvanian time.

Figure 5 gives a fair representation of the uplift in pre-Hoxbar time, and the resulting arrangement of the formations now exposed in the Hunton arch and Tishomingo anticline gives a rather convincing picture to show their original unity. Of course, the areal geology never appeared as in Figure 5, for it required the uplift from the last movements and subsequent erosion to expose the older formations and the granite.

A syncline of considerable magnitude was superimposed on the Hunton-Tishomingo uplift rather early in Pennsylvanian time, and in it were preserved all rocks involved in the original uplift, from the Wapanucka limestone to the Arbuckle limestone. These are now found in the fault blocks of the present Mill Creek syncline.

Arbuckle anticline elements.—Since overlapping Pennsylvanian is the principal criterion for the early Pennsylvanian fold, conformable Pennsylvanian will be the criterion for the late Pennsylvanian fold, and it follows that any portion of these complicated structures which contain conformable Pennsylvanian beds must belong to that fold.

Taff and all succeeding writers have shown that the Glenn formation, as defined by him, redefined by Goldston and Tomlinson, and divided into Dornick Hills, Deese, and Hoxbar formations, is conformable with the lower Paleozoic along the entire south limb of the Arbuckle anticline, which, as shown by Reeds, extends from Pooleville, in T. 1 S., R. 2 W., to Ravia, in T. 4 S., R. 5 E. (Fig. 1).

Tomlinson[40] remarks that the Dornick Hills and the lower part of the Deese formation on the south side of the Arbuckle Mountains are free from the conglomerate which characterizes the same horizons

[40] C. W. Tomlinson, *op. cit.*, p. 48.

near the Criner Hills, and, it may be stated, at Mill Creek. No great angular unconformity interrupts the parallelism of strata from the upper Cambrian Reagan sandstone to the top of the Hoxbar. He makes the same contention for what he calls the "main Tishomingo range," since no coarse, pre-Hoxbar sediments now crop out along its southern margin. What he considers the south margin of the Tishomingo anticline is, in reality, the eastward extension of the south limb of the Arbuckle anticline, as shown by Reeds; hence his argument is of no force in regard to the age of the Tishomingo anticline.

Tomlinson further remarks (p. 43) that the conglomerates in the Hoxbar and Deese suggest that the uplift in the region of the Arbuckle anticline began in Deese time, but the lack of angular unconformity suggests that the source of the conglomerate may have been in the early Pennsylvanian fold, which he locates "north of the Mill Creek syncline."

The Arbuckle-Tishomingo complex must now be further dissected (Fig. 6). Northwestward along the fault which forms the south boundary of the Tishomingo anticline, from its eastern terminus just west of Ravia, to Sec. 7, T. 3 S., R. 4 E., Arbuckle limestone is found on both sides of the fault trace. In this locality, however, successively younger formations on the north side are in contact with the Arbuckle limestone on the south. Near the southeast corner of Sec. 1, T. 3 S., R. 3 E., the fault branches, and a long, narrow outcrop of Caney shale lies between that of the Arbuckle limestone on the south, and those of the various formations of the Tishomingo anticline, on the north. Farther west, it may be seen that this band of Caney shale belongs to the north limb of the Arbuckle anticline, which appears for the first time in the south row of sections in T. 2 S., R. 3 E.

The northernmost fault marks the north limit of the Arbuckle anticline until it reaches Washita River, at which point the fault begins to cut into the north limb of that structure. From here northwestward to the Pontotoc cover, the dividing line between the Tishomingo and the Arbuckle anticlines is the syncline now occupied by Washita River.

Northeast of the Washita syncline occur a number of small sharp folds—domes and basins, which are intimately related to the Tishomingo anticline, and are interpreted as forming the crumpled west end of that feature.

The Arbuckle anticline may now be isolated, by dividing it from the Tishomingo anticline along the fault and syncline above described. Figure 7 gives a hypothetical restoration of the Arbuckle anticline in late Hoxbar time, prior to the last movements, showing it to

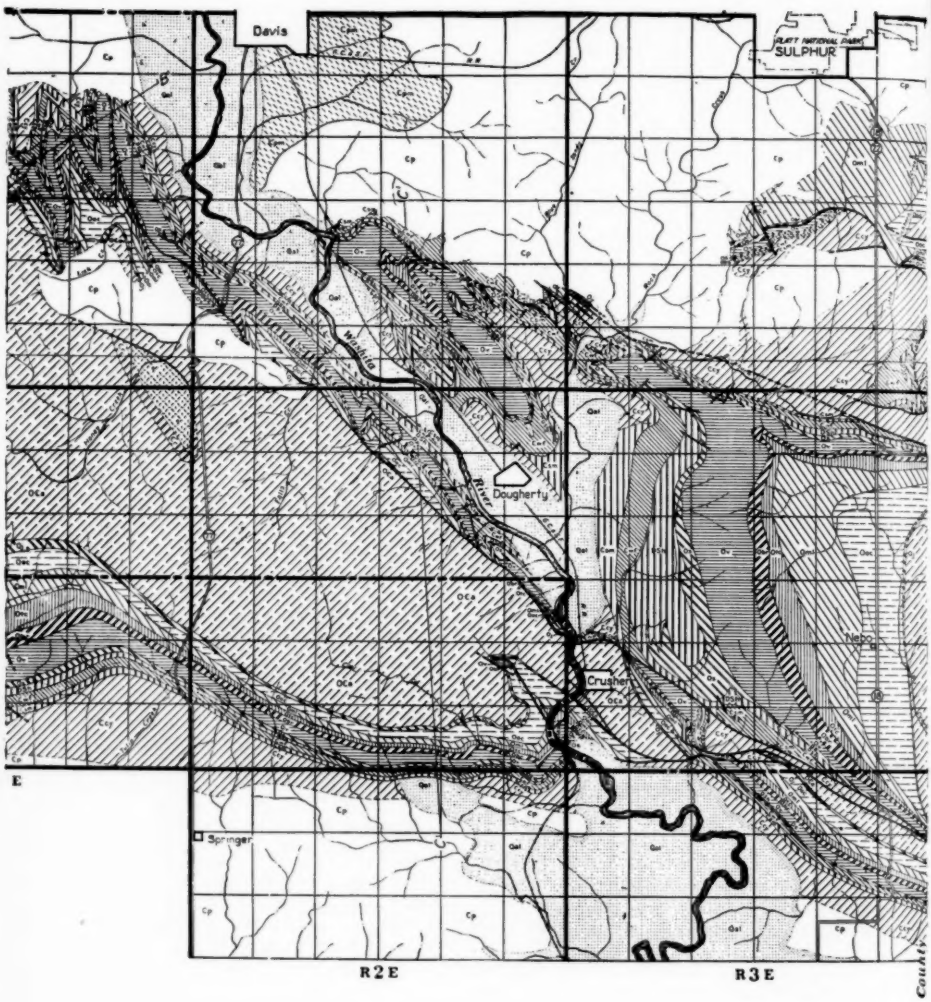
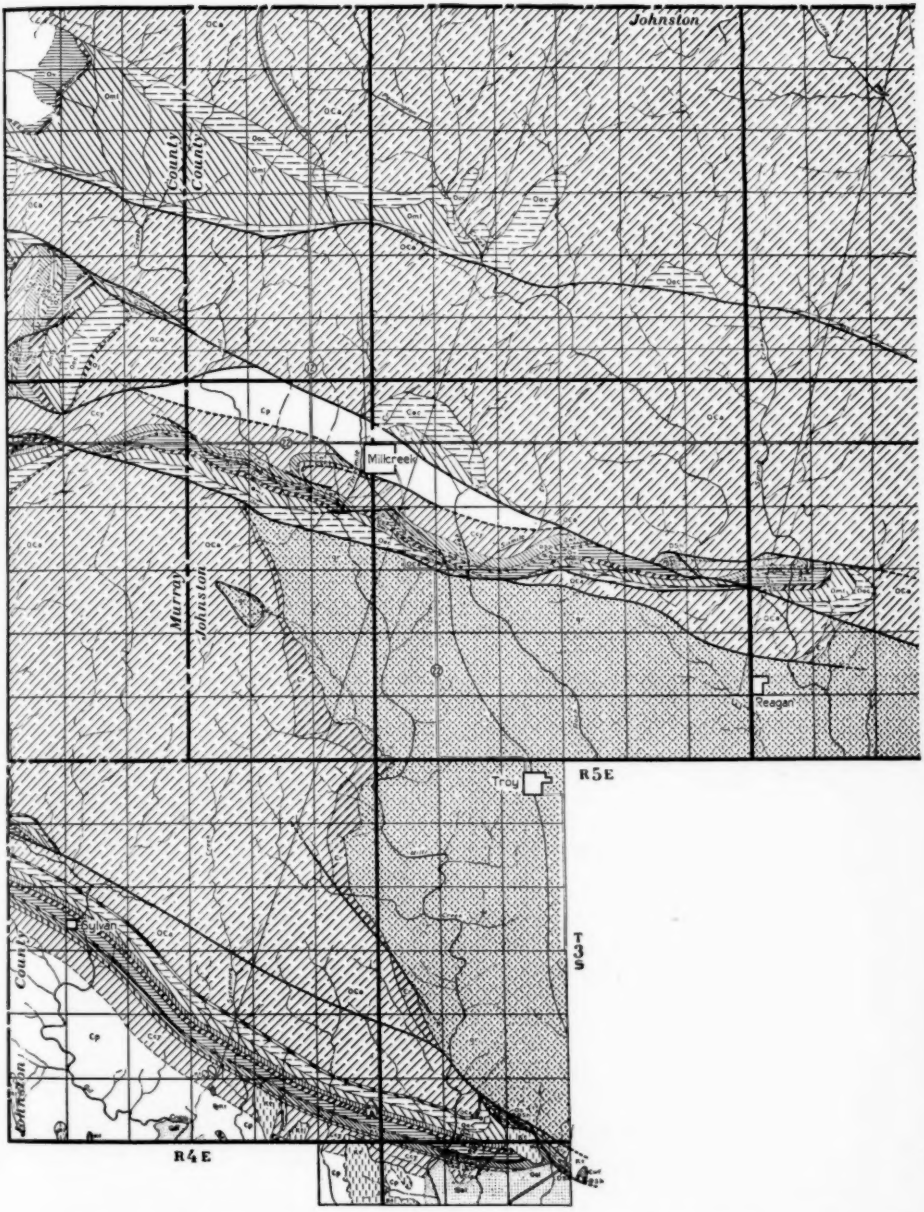


FIG. 6.—Areal map of part of Arbuckle Mountains area, after Decker *et al.*, *Oklahoma Geol. Survey Bull.* 55, Pl. I.



Key to formations: *gr*—Tishomingo granite; *Ꞓr*—Reagan sandstone; *OƐa*—Arbuckle limestone; *Oj*—Joins formation; *Ooc*—Oil Creek formation; *Oml*—McLish formation; *Otc*—Tulip Creek formation; *Obr*—Bromide formation; *Ov*—Viola limestone; *Os*—Sylvan shale; *DSh*—Hunton group; *Cwf*—Woodford shale; *Csm*—Sycamore limestone; *Ccy*—Caney shale; *Cp*—undifferentiated Pennsylvanian; *Cpm*—undifferentiated Permian Red-beds; *Kt*—Trinity sandstone; *Qal*—alluvium.

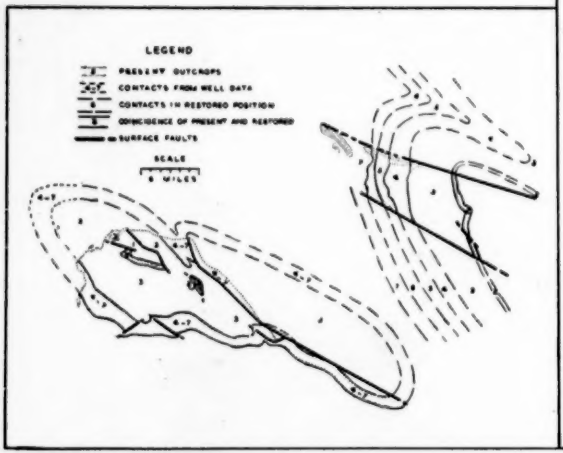


FIG. 7.—Hypothetical restoration of Arbuckle anticline in late Hoxbar-Ada time, showing its original form as an elongate anticline, cut from end to end by a fault which transgresses from near south side of its crest, in its eastern end, to north side of its crest, at west end. Subsurface control at northwest end from Roth, "The Robberson Field," *Oklahoma Geol. Survey Bull. 40*, Vol. II, Fig. 23, p. 154. Key to formations: *1*—granite; *2*—Reagan sandstone; *3*—Arbuckle limestone; *4*—Simpson group; *5*—Viola limestone; *6*—Hunton-Sylvan; *7*—Caney-Woodford.

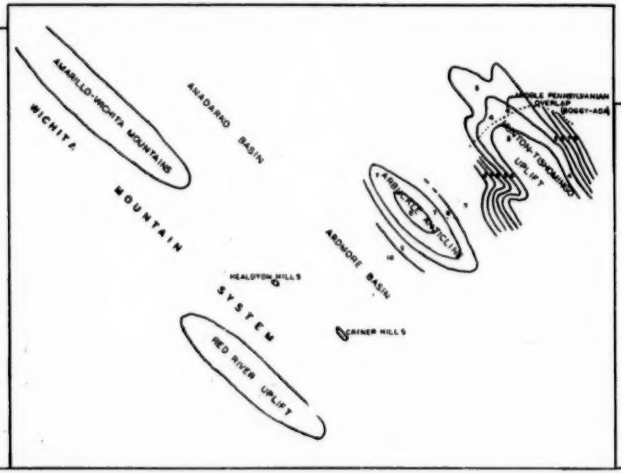


FIG. 8.—Sketch map showing hypothetical restoration of areal distribution of formations in Arbuckle anticline and Hunton-Tishomingo uplift in late Hoxbar time, during early stages of Arbuckle anticline orogeny; and relation of those folds to Ardmore basin and Wichita Mountains system. *3*—Arbuckle limestone; *4*—Simpson group; *5*—Viola limestone; *6*—Hunton and Sylvan; *7*—Woodford, Caney, and Springer; *8*—Wapanucka and Atoka-Dornick Hills; *9*—Deese; *10*—Hoxbar. Width of area approximately 300 miles.

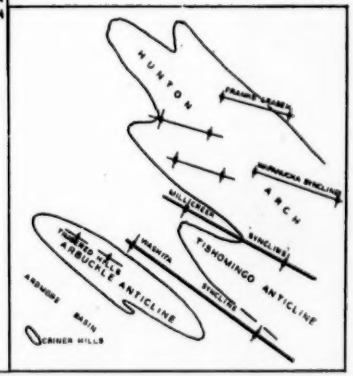


FIG. 9.—Sketch of Arbuckle region in late Hoxbar-Ada time, subsequent to folding and prior to overthrusting, showing major structural features which were overthrust in last stages of Arbuckle orogeny. Heavy lines indicate present traces of largest overthrusts.

be an elongate anticline which was later cut almost from end to end by a fault which transgressed from near the south side of the crest in its eastern end, to the north side of the crest at its west end, where it practically died out in a series of tight folds. The previous remarks about the areal geology shown on Figure 5 apply equally to Figure 7, since the present distribution of formations in the Arbuckle anticline resulted from the final movements and subsequent erosion.

EARLY AND MIDDLE PENNSYLVANIAN PALEOGEOGRAPHY

In Atoka time, a land mass stood in the position now occupied by the Hunton arch and Tishomingo anticline, trending northwest and southeast, and extending much farther, in both directions, than the present outcrop of these two folds. Well records indicate that it extended northwest at least as far as Pauls Valley, and evidence given by Powers[41] indicates that it extended southeastward into Bryan County, Oklahoma, and it may have extended much farther, beneath the present Ouachita overthrust.

By McAlester time, the crest of the Hunton-Tishomingo uplift had been eroded to the Hunton limestone, while the northeastern flank was being submerged by encroaching seas. Erosion of the crest, accentuated by intermittent uplifts, accompanied progressive encroachment of the sea on the flanks, and by Boggy time, Viola limestone had been exposed. Then followed a rather extensive emergence, succeeded by renewed encroachment, and by Francis time, the entire northwest end of the Hunton-Tishomingo land mass had been submerged.

Some evidence indicates that granite may have been exposed as early as Wewoka time. Small amounts of arkose reported by Morgan[42] in the Wewoka formation and noted in well cuttings may be interpreted as evidence that granite was exposed in the heart of the Hunton-Tishomingo uplift. Morgan, however, was inclined to think that the granite came from some source other than the Arbuckle Mountains region, saying

> The igneous material . . . [in the Wewoka formation] is darker and more fine-grained than the . . . arkosic material . . . in the Pontotoc beds and it seems improbable that the two were derived from the same source. The nature of the igneous material in the Pontotoc strata and the fossiliferous limestone fragments associated with it clearly indicates that it was derived from the Arbuckle Mountains. The source of the igneous pebbles in the Wewoka occurrence, however, is unknown. The pebbles are mostly small and well rounded and may have been brought in from a distant region.

[41] Sidney Powers, *Bull. Geol. Soc. Amer.*, Vol. 39, footnote p. 1045.

[42] George D. Morgan, *op. cit.*, pp. 94–101.

The absence of arkose in all other pre-Pontotoc formations suggests that no granite areas were within reach of the streams which drained northward.

On the southwest flank of the Hunton-Tishomingo land mass, somewhere in the vicinity of the present Mill Creek syncline, a deep syncline had developed, preserving from later erosion all the rocks involved in the original uplift. Other, less important synclines were formed in the Pauls Valley region, and probably elsewhere.

Pebbles in the Boggy shale show that the Viola limestone was exposed on the Hunton-Tishomingo arch during that period. It is probable that the Simpson and even the Arbuckle rocks may have been exposed in Francis time, but the absence of arkose shows rather definitely that no important granite areas were available to the streams which flowed into the Francis sea.

Southwest of the Hunton-Tishomingo land mass, and parallel with it, was a low land or series of islands, part of the extensive Wichita Mountains system of Powers and van der Gracht, including the Criner Hills. Between the land of the Wichita system and the Hunton-Tishomingo land mass lay a broad syncline, receiving sediments from both uplands, and probably from other near-by sources, and covering the present Arbuckle anticline and Ardmore basin. A series of rocks was deposited in this basin which differs, in facies and sequence, from the material which was being laid down simultaneously in the McAlester Coal basin northeast of the Hunton-Tishomingo land mass. In all probability, the two basins were never connected.

It is not to be supposed that conditions in the Arbuckle region were quiescent throughout the entire period from Wapanucka time to Hoxbar time. In fact, there is strong evidence to show several minor uplifts or oscillations of the Hunton-Tishomingo axis during the intervening time, and while the area of the Arbuckle anticline was mainly negative, some local movements took place which produced the unconformities found in the Tatums pool, and elsewhere in that vicinity.

LATE PENNSYLVANIAN OROGENY

Late in Hoxbar time, tangential forces from the southwest rejuvenated the older folds of the Wichita Mountains system, and the entire system was moved northward toward the Hunton-Tishomingo buttress. The Ardmore-Arbuckle geosyncline was greatly compressed, and the rocks folded into the Arbuckle anticline (Fig. 8). As the stresses continued, the eastern part of the Wichita system was thrust still farther north, apparently moving on a pivot, with the west end of the Amarillo mountains remaining stationary. This intense thrust-

ing at the eastern end resulted in minor folds developing on the major axes (Fig. 9), first in the Arbuckle anticline. Later, in the Hunton-Tishomingo arch, most of the folds became asymmetrical, and many were finally overturned toward the northeast. In the final stages of movement, the major anticlines broke on their overturned axes, finally developing into overthrusts and overriding the adjacent synclines.

The Arbuckle anticline was thrust far northeast of its original position, its south flank overriding a considerable distance onto the Hunton-Tishomingo uplift. The magnitude of the overthrust, in the Arbuckle anticline, decreased rapidly from southeast to northwest, where the crustal shortening was taken up mainly by complex folding, as seen southwest of Dougherty.

Thrusts developed along the axes of the folds, and two blocks of pre-Cambrian granite porphyry were thrust over the Reagan sandstone onto Arbuckle limestone, in the Timbered Hills.

The stresses were transmitted to the Tishomingo-Hunton uplift with several different results. A series of compact folds was formed near Dougherty, at the west end of the Tishomingo anticline. The Tishomingo anticline itself was moved northward a great distance, in an overthrust second in magnitude only to the thrust of the southeast end of the Arbuckle anticline, overriding the syncline to the north, breaking off blocks of the rocks present in it, and moving them northward to their present position near Mill Creek. The Tishomingo fold was greatly uplifted, bringing the granite within reach of subsequent erosion.

The stresses also affected the Hunton arch, and produced the downwarps of the Franks graben, Wapanucka syncline, other minor synclines, and some minor thrusts.

Erosion no doubt kept pace with folding, so that, by Pontotoc time, the area was pretty well base-levelled, and large areas of Arbuckle limestone and granite had been exposed. Then a considerable portion of the uplifted area was submerged, and the outlying portions of the mountains of the Arbuckle uplift were buried in their own débris.

Patches of Pontotoc conglomerate near the crest of the Arbuckle anticline indicate that the Pontotoc sea may have covered a considerable portion of the present mountains. The elevation of these patches, and the steep dip on the Pontotoc, on the north flank of the Arbuckle anticline, suggest that post-Pennsylvanian movements may have rejuvenated that fold. The steep and erratic dips on the Pontotoc in the vicinity of the major faults, particularly on the north

limb of the Arbuckle anticline, indicate that post-Pennsylvanian movements have also taken place along the fault planes.

EVIDENCE OF THRUSTING

The better known overthrusts of the United States are marked by unmistakable stratigraphic relationships, and in many instances by measureable fault planes. In the vicinity of Glacier National Park, Montana, the Lewis overthrust was recognized by the fact that an outlier or *klippe* of the Cambrian or pre-Cambrian Belt series was found resting on rocks of Cretaceous age.

Dake[43] suspected that the Ouachita Mountains in southeastern Oklahoma had been thrust northward, because of the decided difference in facies between the clastic rocks of those mountains and the equivalent marine rocks in the adjacent Arbuckle Mountains, only 15 miles distant.

The Arbuckle overthrust, postulated in this paper, can not, at this time, be demonstrated by exposures containing a measureable fault plane. Nor can it be shown by marked differences in age, lithology, or facies of the rocks. It must, therefore, be inferred from other evidence.

The first line of evidence is the hypothetical restorations shown in Figures 5 and 7. If the folds originally had such forms, their present forms could have resulted only from horizontal thrusting. Conversely, the present relationships and distribution of the various formations in the Arbuckle Mountains can be better explained by such thrusting than by any hypothesis hitherto suggested.

The second line of evidence is found in the areal geology and stratigraphy of the region. Certain stratigraphic anomalies are found, which may perhaps be due to normal lateral gradation, but which seem to be more logically explained by the assumption that stratigraphic sections now near each other were deposited considerable distances apart, and were brought into proximity by lateral thrusting movements.

Certain of these anomalies have already been indicated on page (582) under Periods of Folding. The most striking instances are in sections of the Simpson group in and adjacent to the Mill Creek syncline. Throughout the area of the Arbuckle and Tishomingo anticlines, the Simpson is made up of five formations, designated, in ascending order: Joins, Oil Creek, McLish, Tulip Creek, and Bromide.

All these formations are present in Sec. 7, T. 2 S., R. 4 E., though one-half mile north, in Sections 5 and 6, one of the fault blocks of the

[43] C. L. Dake, "The Problem of the St. Peter Sandstone," *Bull. School of Mines and Metallurgy* (University of Missouri, Rolla), Vol. 6, No. 1 (August, 1921).

Mill Creek syncline contains only four formations, the Tulip Creek being absent. Still greater change may be noted between this last point and the east-central part of T. 1 S., R. 3 E., a few miles northwest, where only three formations are found, both the Joins and Tulip Creek being absent, and this sequence prevails throughout the entire area of the Hunton arch. In a block in Sec. 8, T. 2 S., R. 5 E., four formations of the Simpson group are found, and in another block in Sec. 20, T. 2 S., R. 6 E., 6 miles away, only three are present.

This group of rocks, in an area 7 miles wide and 36 miles long, contains five formations, but changes abruptly, in a distance of 4 miles, across a narrow fault zone, to only three formations, and this sequence then prevails over an area of 18 by 32 miles. Such a striking contrast is at least highly suggestive that two distinct sections of rocks were originally deposited in rather remote parts of a basin, and have been moved to their present positions of proximity by thrusting.

The third line of evidence is to be found in the dip of the rocks—asymmetric folds, overturned folds, and overturned beds. These features have already been discussed by the writer,[44] but some of the more striking examples are repeated here.

Dip observations shown on the structure sheet of the *Tishomingo Folio* indicate that the Tishomingo anticline is asymmetrical, with dips up to 65° on the north limb, and from 20° to 35° on the southwest limb. Asymmetry in the Arbuckle anticline is evidenced by outcrops of the pre-Cambrian core, which are found much nearer the north than the south flank of the fold. Minor asymmetric folds are common.

Several overturned folds have been observed by the writer, and numerous others probably are to be found. Figures 10 *A* and 10 *C* are cross sections of an overturned fold in the valley of Honey Creek, on the north side of the Arbuckle anticline, and of the overturned axis of the Dougherty anticline.

Overturned beds are common phenomena in various parts of the mountains, with dips ranging from 89° to 45°, with Sylvan resting on Hunton, Simpson on Viola, Woodford on Sycamore, and the like. Figure 10 *D* is a cross section in the vicinity of an abandoned asphalt mine 2 miles northwest of Franks, at which locality the Sylvan shale rests on Hunton limestone, and both dip southwest at an angle of 80°.

Virtually the entire north limb of the Arbuckle anticline contains overturned beds. Southeastward from the mouth of Honey Creek, many excellent exposures of all beds from the Caney shale down to the

[44] Robert H. Dott, "Overturned Beds in Arbuckle Mountains, Oklahoma," *Bull Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 7 (July, 1933), pp. 865–68.

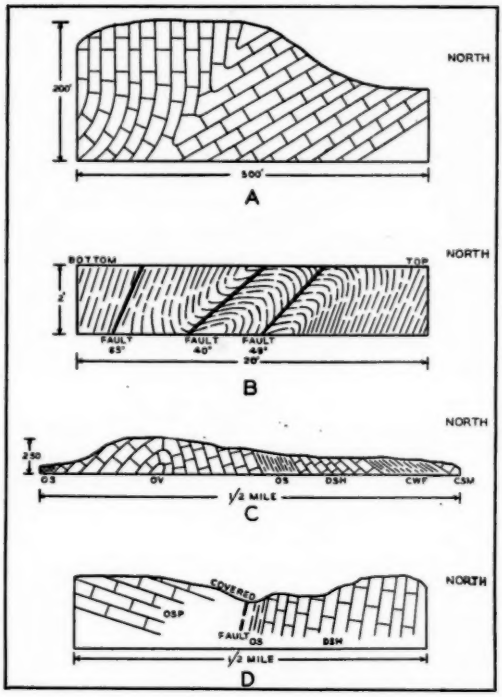


FIG. 10.—Sketch cross sections, showing overturning in surface exposures.

A. Part of overturned anticline in Viola limestone, showing adjacent syncline. Located near center of Sec. 30, T. 1 S., R. 2 E., in east bluff of Honey Creek, and seen from high fill on U. S. Highway 77, about 1.25 miles south of Washita River bridge. Beds in top of cliff dip vertically, and near base dip southwest at angles of 45°–55°—overturned toward northeast.

B. Small crop of overturned Sylvan shale near center of W. ½, Sec. 11, T. 2 S., R. 2 E., in east bank of small creek in which Ardmore Boy Scout camp is located, opposite town of Dougherty, south of Washita River. Beds dipping southwest at angles of 69°–77° overlie Hunton limestone, which crops out 100 feet north. The outcrop contains three low-angle thrust faults, two anticlines, and a syncline, and may be said to represent Arbuckle structure in miniature.

C. Section along A. T. & S. F. R. R., where it crosses west end of Dougherty anticline, in SW. ¼, Sec. 21, T. 1 S., R. 2 E. Viola limestone occurs in axis of fold, whose north limb is overturned northeast. Beds of Viola limestone dip southwest at angles of 77°–89°.

D. Section across Big Spring Creek in Sec. 28, T. 2 N., R. 6 E., near asphalt deposits, 2 miles northwest of Franks. In bed of creek, Sylvan shale rests on Hunton limestone, dipping south at 80°. South of covered area, members of Simpson group dip north at angles of 10°–20°. Fault can not be seen, but is interpreted as thrust fault, with dip at least as flat as that of Hunton and Sylvan formations.

Legend: *Osp*—Simpson group; *Ov*—Viola limestone; *Os*—Sylvan shale; *DSh*—Hunton terrane; *Cwf*—Woodford shale; *Csm*—Sycamore limestone. Note: Sections *A*, *B*, *C* occur in west-facing bluffs, but have been oriented to conform to conventional practice, and with sections in Figure 11.

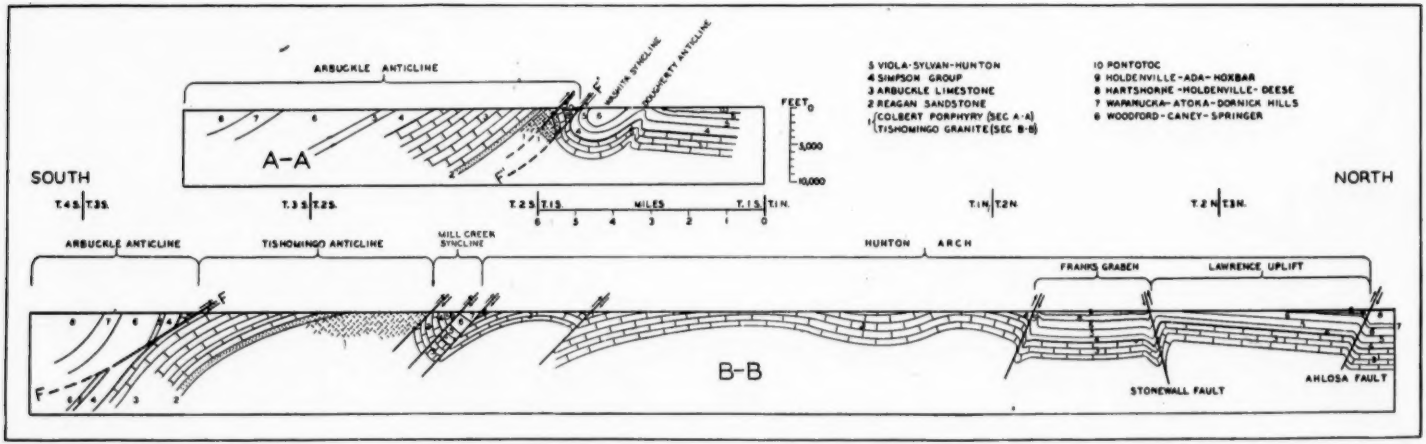


FIG. 11.—Structure sections showing Arbuckle structure interpreted as resulting from thrusting. *AA* is across Arbuckle anticline; *BB* across Hunton-Tishomingo uplift. Fault *FF* and *F'F'*, in the two sections, is main thrust plane upon which Arbuckle anticline has overridden Hunton-Tishomingo uplift. Dip of strata taken, where possible, from observations of Taff, Morgan, and the writer. Horizontal and vertical scales are equal. See Figure 2 for location.

Simpson group may be seen, either along the road, or a short distance up the streams which cross it. Without exception, these exposures exhibit dips overturned from 1° to 45° (Fig. 11).

One exceptionally interesting outcrop was found in the valley of a small creek which enters Washita River opposite Dougherty, and in which the Ardmore Boy Scout camp is located. Sylvan shale is exposed in the right (east) bank of the creek, about 0.25 mile upstream from the main road. Here, in an exposure 2 feet high and 20 feet long, the Sylvan dips south at angles ranging from 69° to 77°, overturned northeast (Fig. 10 *B*). Within the exposure are three faults, a syncline, and two anticlines. The axial planes of the anticlines dip southwest, and the folds are overturned northeast. The faults also dip southwest, one at 40°, another at 49°, and the third at a greater angle.

Every asymmetric fold observed in the region has the north limb the steeper. The axial planes of overturned folds are all inclined southwest, and all the overturned beds dip southwest. These conditions are the result of tangential forces acting from the southwest.

The writer's interpretation of the structure of the Arbuckle Mountains is graphically summarized in the structure sections shown in Figure 11, in which all faults are shown as thrust faults. Following an established principle of pre-Cambrian geology, that a small exposure, or even a hand specimen, is a key to major structure, the exposure of Sylvan shale in the creek opposite Dougherty (Fig. 10 *B*) is taken as a miniature representation of the structure of the whole mountain system, with overturned folds and thrust faults. Lacking other evidence on the dip of the major fault planes, they are assumed to dip at angles which are no greater than those at which the minor faults are inclined, as is shown in Figure 11.

SUMMARY

In the foregoing discussion, the writer has endeavored to establish the following propositions.

1. The Arbuckle area contains two uplifts, formed at different times in the Pennsylvanian, one near the beginning, the other near the end.

2. These major features should be designated by specific names, the Hunton-Tishomingo uplift and the Arbuckle anticline, and such vague and unsatisfactory terms as "eastern Arbuckles" and "western Arbuckles" should be abandoned.

3. Overthrusting, which concluded the late Pennsylvanian movements, was a major factor in producing the present distribution of the rocks in the general Arbuckle area.

4. Field evidence of major overthrusting is present in asymmetric folds, overturned folds, overturned beds, and minor thrust faults.

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TECTONICS OF SOUTHEASTERN CAUCASUS AND ITS RELATION TO THE PRODUCTIVE OIL FIELDS[1]

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ABSTRACT

The principal object of this article is to show that in the zone of submergence of the Caucasian Range, which is also the zone of deep subsidence, peculiar tectonic forms were originated in the creation of which vertical pressure played an outstanding part. These forms received the name of diapiric folds. These structures, together with mud volcanoes and oil-bearing formations, form one genetic whole. In order to prove this, his fundamental thesis, the writer has made use of the extensive stratigraphic and tectonic material, as well as the data of the geological history of this region. This material has been accumulated as a result of self-sacrificing labors of the old and the young generation of geologists of the Land of the Soviets.

INTRODUCTION

Foundations of the geology of the Caucasus region are justly credited to the Academician Abich, who, beginning with the sixties of the past century, devoted particular attention to its study. None of the many geologists now investigating this region can dispense with careful study of his works, which are still considered fundamental.

After Abich, the study of the Caucasus was continued by other eminent geologists, for example, Academician Andrusov, Professor Bogdanovich, and the late D. V. Golubiatnikov. The last devoted over 30 years to the Apsheron Peninsula and its oil fields.

The stratigraphy of the formations and especially the tectonics of the Caucasus still have many problems to be solved, although much more has been achieved in this direction during the last 15 years than in the whole pre-Revolutionary period. During these years much attention has been given not only to the study of the outer parts of the Caucasus, which are now covered by a complete geological survey on a large scale, but also to the central parts of the Caucasian Range.

Though the central districts still lack a complete geological survey

[1] Read in brief form before the Section on the Geology of Petroleum, of the 16th International Geological Congress, at Washington, D. C., July 24, 1933. Manuscript received, August 19, 1933. The editors acknowledge the editorial assistance of Basil B. Zavoico, consulting geologist, New York City.

[2] President, United Geological and Prospecting Trust of the U. S. S. R., Leontievsky per. 25 Kw. 14. Member of the Soviet Union Academy of Science.

even on a small scale, the number of cross sections in the most important directions has been recently increased. However, in spite of the fact that a number of geologists are now working in the Caucasus, considerable time will elapse before we shall get a complete geological survey of this remarkable range and shall be able to get, not a hypothetical, but a true conception of its geological structure. Only then shall we be able to solve problems of great theoretical and practical importance.

Some parts of the Caucasus have been sufficiently investigated to afford a fairly accurate conception of their geological structure—those parts which are being exploited for their mineral wealth, and particularly the oil-field districts. The best known among the oil districts is in the southeastern Caucasus, including the famous oil fields near Baku on the Apsheron Peninsula. For the southeastern Caucasus there is a map on a scale of 1:42,000; for individual oil fields, on a scale of 1:8,400, and even 1:4,200 for the Bibi-Eibat oil field.

This whole region is of particular interest from a theoretical as well as from a practical standpoint. It contains numerous mud volcanoes presenting phenomena of the greatest theoretical importance. It includes hundreds of places with indications of petroleum, and covers several thousand square kilometers, whose wealth is amply proved by the world-known oil fields of the Apsheron Peninsula.

Thus it is obvious why, out of the whole vast problem of the geological structure of the Caucasus, the writer has selected only a small part, namely, the tectonics of the southeastern part of the Caucasian Range and its relation to the oil fields and mud volcanoes.

Area

The area of the southeastern Caucasus includes the broad region bounded on the north by Samour River, on the east by the Caspian Sea, on the south by the Kura Valley, and on the west by the meridian passing through the top of Shah-Dag Mountain (elevation, 4,242 meters) and the valley of Pirsagat River. This region may be subdivided into: (1) the east end of the Main Range; (2) the Apsheron Peninsula on the east and the region of the Kabristan Steppes on the west, consisting of northern Kabristan, bounded on the south by Sumgait River and its tributaries, middle Kabristan, located between Sumgait River on the north and Djeyran-Khechmes River on the south, and southern Kabristan, whose southern border is formed by the Kura Plain, on the northern edge of which passes the Transcaucasian Railroad. The Kura Plain is covered by the extensive Saliani Steppes, which constitute the extension of the oil-bearing

region of the southeastern Caucasus southward to the border of Persia.

Tectonic Theories of Entire Caucasus

Although the writer has chosen as the subject of this article the tectonics of only one part of the Caucasus, still he believes that its peculiarities may be best understood and explained if he also touches, very briefly, upon the current views of the Soviet geologists on the principal tectonic features of the whole Caucasus. In this respect the latest work of the geologist, W. P. Rengarten, deserves special attention. It represents the latest attempt to systematize all the principal data on Caucasian tectonics. Almost at the same time a similar study was made by the geologist, A. P. Gerasimoff. These scientists have utilized the vast volume of data gathered in the course of geological investigations of the Caucasus during a long period, especially since the advent of the Soviet Republic.

Abich.—Still it must be mentioned at the beginning that the first generalization about the structure of the Caucasus is to be found in the works of the Academician Abich, who was the first to point out the difference in structure between the northwestern and the southeastern Caucasus. According to his conception the main fold of the northwestern part is overthrown toward the south, and on the southeast a fault system was developed which divided this part of the Caucasus into two definite trends, one coinciding with the general direction of the range and the other almost perpendicular to it. At the crossing of these trends, according to Abich, all the most important mud volcanoes of the southeastern Caucasus are located. Considerable subsidence occurred along the fault lines. Thus he thinks that the southern part of the main fold along the rift, coinciding with the general direction of the Caucasian Range, was submerged under the Kura Valley. He was the first to discover, along the line of this rift, in the region of Shemakha, on Nial-Dag Mountain, exposures of volcanic rocks: andesites and basalts. The southeastward extension of this line strikes the Aliat Ridge where dozens of mud volcanoes are located along the line of rift.

This area, accordingly, is particularly subject to earthquakes. The Shemakha earthquake of 1902 was of especially great violence. Abich's system comprises the fault lines of Dagestan, the subsidences in the regions of the northern and the southern Caspian, and other movements.

Abich had an enthusiastic follower in the person of Bogdanovich, who based his research in the southeastern Caucasus on the works of

Abich, regarding him as his teacher and as the creator of the geology of the Caucasus.

Bogdanovich.—In his fundamental work on the Dibrara system, Bogdanovich tries to give a theoretical foundation for Abich's views. Upholding the point of view of Suess, who held that the eastern continuation of the Caucasus is the western part of the Tian-Shan folds, or the Altaides according to Suess terminology, and the western continuation forms the ranges of the Alpine folds, Bogdanovich regarded the Caucasian Mountains as the link between the Altaides and the Alpides.

Since it was acknowledged that during the orogenic movements in the Alps the stresses, or the movements of the masses, were directed northward, which resulted in the overturning of folds in the same direction, but that, in the Altaides, the stresses came southward from the Siberian hard plate,[3] it is clear that the Caucasus, as an intermediate link, had to undergo twisting stresses. The tectonics of both termini can be explained by the predominating pressure on one or the other end, coming from the direction of the rigid, stable massives. Such a type of predominating pressure took place on the northwest end, forming overthrown isoclinal folds. On the opposite southeastern end, where the pressure was weaker, arose a fan-like system of diverging fault lines, which, according to Bogdanovich, fully correspond with the theoretical assumptions. These ideas of Abich and Bogdanovich long persisted among Caucasian geologists and their recurrences can be found even in some comparatively recent works.

This is exactly what could be expected when it is remembered that until very recently no one studied the great questions raised by them. It is natural that their works, and especially those of Bogdanovich, dealing with the tectonics of the southeastern Caucasus, are still regarded as fundamental. It must be remembered, however, that the schemes and the conclusions of both Abich and Bogdanovich were based on a very few facts, referring to a small number of points and districts, whereas the vast expanse of the Caucasus remained completely unexplored.

They have had to establish the fundamentals of the geological structure of the Caucasus, the principles of its stratigraphy and of its tectonics. It is quite natural, therefore, that as time goes on, and with the application of regional, and especially of detailed, geological surveys, their ideas have been and will be further modified and corrected. Apparently it will be necessary to get away from general

[3] For definition of "hard plate," see p. 608.

schemes and broad generalizations based on a meager stock of actual observations.

Goubkin et al.—The writer and other pupils of Abich and Bogdanovich had to use a different method in studying the geology of the southeastern Caucasus—the method of complete geological surveys on a large scale accompanied by detailed geological explorations.

Among the fundamental principles established by Abich and Bogdanovich, our special attention is held by the idea according to which the extreme southeastern part of the Caucasus, including the Apsheron Peninsula, is a direct prolongation of the main Caucasian Range not only in the orogenic, but also in the tectonic, sense.

Bogachev.—This seemingly natural and simple thought, however, met with objections. Professor V. V. Bogachev, for example, thinks that

> according to data contained in literature nothing can be said in favor of submersion of the axis of the fold or of spreading of the latter. But the presence on the eastern terminus of the fold of the Nial-Dag-Lagich volcanic rocks and some unconformity of axial folds to the west and to the east of the Velvely-Chai Canyon, impels us to assume here a rift in the Main Range and a displacement of sections,

and, on account of this, the Upper Tertiary folding of the Apsheron Peninsula "may be regarded as an independent one." The writer believes that no one will find such arguments very convincing.

Rengarten.—V. P. Rengarten puts forth an original opinion, that the Apsheron Peninsula is a part of the Kura hard plate, upon which, in the central and partly in the eastern Caucasus, was thrust from the north the folded zone of the southern slope of the Caucasus. He holds that the main Caucasian Range terminates in the east at the cliffs of Beshbarmak and of Cape Kiliazin on the Caspian shore, far north from the Apsheron Peninsula. This opinion corresponds with the recent views of some geologists on the tectonics of the Caucasus.

According to this viewpoint, the general tectonic structure of the Caucasus appears as follows: north and south of the main Caucasian Range are two hard plates, (1) the pre-Caucasian, consisting of the Stavropol plate with two deep depressions, the pre-Kuban and pre-Terek, and (2) the trans-Caucasian, divided by the Suram saddle into the Rion and the Kura plates.

The depressions of Kuban and Terek, constituting a natural extension of the still deeper depressions of the Azov and Caspian seas, originated after the deposition in the Caucasian region of the Lower Cretaceous sediments. Until that time they formed an integral part of the Stavropol plate.

South of the trans-Caucasian plate is the second, the more southerly folded zone of Armenia and of the Adjaro-Akhalzykh region. Between the pre-Caucasian and the trans-Caucasian hard plates, in the Jurassic and Cretaceous ages, existed a narrow synclinal basin, which formed part of the large geosyncline, known as Tethys. In this narrow geosyncline accumulated a mass of deposits many thousands of meters in thickness. Part of this basin, corresponding with the present southern slope of the Main Range, was filled with deposits of Flysch character, while north and south of this line normal, marine beds had been deposited.

In the course of orogenic movements resulting from the crustal shortening of the earth and from tangential stresses, the hard plates moved one toward the other, causing compression of the geosynclinal deposits and the formation of isoclinal folds, overthrown one over the other. As this movement usually took place along steep fault planes and rarely along gently sloping planes, overlapping of the *nappe-de-charriage* type was formed.

Similar phenomena took place also in the more southern geosyncline only with the formation of folds overthrown toward the north. Thus the northern end of the trans-Caucasian plate was covered by folds of the southern slope zone of the Main Range, and its southern end by folds of the Armenian zone and of the Adjaro-Akhalzykh Range.

The foregoing scheme of the tectonic structure of the Caucasus leaves several points that are not sufficiently clear. First one wonders on the basis of what data the existence of the trans-Caucasian hard plate was established, and why this is a plate and not some other form of rigid massif, such as the American geologists call "Median mass," which can be exemplified by the western and central cordilleras in the northern Andes in South America or the Goby-Manchurian massives in eastern Asia.

Arkhangelsky. Definition of "plate."—By the term "plate," at least in Soviet geological literature, somewhat different geological structures are understood. Academician Arkhangelsky designated by this term

> extensive sections of the earth's crust composed principally of enormous masses of strongly metamorphosed and dislocated pre-Cambrian formations —crystalline shales, gneisses, and different volcanic rocks.

The basic masses are covered by

> normal non-metamorphosed, generally not dislocated, or slightly dislocated sedimentary formations of the most varied ages, beginning with the Cam-

brian and ending with the Quaternary. Besides the sedimentary formations we also find on the plates some volcanic post-Eozoic rocks. . . . We note, therefore, as a characteristic feature for plates, a very sharp difference between the pre-Cambrian strata forming the foundation, and the younger formations covering them; the first are strongly dislocated and metamorphosed.

If we should compare this definition of a plate, which fits the eastern plate of Europe and perhaps the Stavropol plate, with the characteristics of the Rion and the Kura plates, given by Rengarten in his book "Tectonic Characteristics of the Region of Folds in Caucasus," then these geological structures can not be called plates. Should we believe that under the Mesozoic beds of the Kura plate, "there is a granite substratum at a moderate depth," this geological formation as well as the Rion "plate" should be classified with the type of intermediary massives ("Median mass"). But this is not the point. Neither the existence of Mesozoic masses, nor the presence of a granite substratum under them has been proved for the Kura depression. Everything in this hypothesis is based on a general assumption and not on facts. On the one hand, the description of the Kura plate begins with the statement that

the extensive depression to the east of the Soram elevation is characterized in the first place by the absence of outcroppings of the ancient Paleogene (page 189)

and on the other hand, we read a few lines below:

the Mesozoic beds of the Kura plate are formed not by the Flysch facies but by the volcanic porphyries and the organic limestones. This alone suffices to account for the rigidity of the Kura plate.

On what ground, then, is this conclusion reached? On the ground that in the basin of Geok-Chai River Mesozoic formations were found not in the Flysch but in the porphyritic facies of volcanic origin. This fact alone is not proof because Geok-Chai River cuts across the Nial-Dag-Lagich volcanic massive. In its vicinity volcanic tuffs of Mesozoic character could be formed. But what justification is there for extending this condition to the whole Kura Valley and for denying the presence there of Mesozoic beds of Flysch facies, especially since "outcroppings of the ancient Paleogene" throughout the whole Kura depression are absent? And perhaps there were not any Mesozoic formations on that plate at all, if it consisted at that time of a mass of granite substratum, from which, according to the author, material was eroded to form large boulder conglomerates with granite pebbles in the Lower Cretaceous and the Upper Eocene deposits.

Incidentally, the presence of these conglomerates is the only proof that in the Kura Valley "not very deep under these Mesozoic beds we

have a crystalline granite substratum." Perhaps all this is true: the Kura plate is a rigid plate and has a granite substratum and very rigid Mesozoic rocks, the presence of which alone could account for its rigidity—but still this is only a daring and a totally unfounded hypothesis.

It probably would not be worth while to argue against it, but the

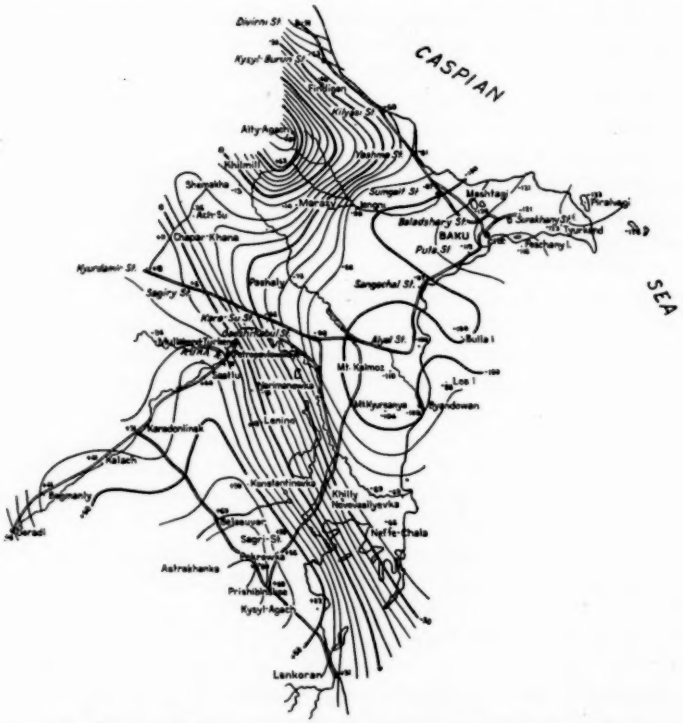

FIG. 1.—Pendulum observations of relative gravity in east Azerbaijan (southeast Caucasus), 1931. Scale, 1:2,100,000.

fact is that the Kura plate extends far eastward: it comprises the Kabristan Steppes and the Apsheron Peninsula. The statement that under these regions, just as under the whole Kura plate, the granite substratum lies not very deep, is a generalization which can not be proved. And here is the reason. In 1931 a magnetic and gravity survey was made of eastern Azerbaijan and the resulting map showed that the isogammas −130, −120, and −100 pass through the Apsheron

Peninsula, that central Kabristan is outlined by the isogamma −100, and that northern Kabristan, along the lower part of Kura River and in the Saliani Steppes, is crossed by the isogammas ranging from −100 to −50. The zero isogamma, dividing the region of negative values of the index of acceleration of gravity from the region of its positive values, passes through the middle of the Kysyl-Agach Gulf on the Caspian Sea and through a point located somewhat east of the confluence of the Kura and Araks rivers.

Isogamma +50 indicates the rise of heavy masses northwest of Lencoran and the apex of this rise near Alty-Agach on the north. The highest index at both these points is +80, and the lowest, on the Caspian Sea near Artem Island (formerly Holy Island), is −138. The amplitude of fluctuations in the acceleration of gravity, therefore, equals 218 units. With respect to the eastern part of the Kura depression at the confluence of the Kura and Araks rivers, the illustration we have chosen confirms to a certain extent the assumption of Rengarten and other geologists, that here the heavy masses really lie not very far below the surface.

On the other hand we see that the whole eastern part of Azerbaijan, including the Apsheron Peninsula, forms a deep depression, in which the heavy masses lie at great depth. The geologic data are fully in accord with the results of the gravity survey.

The writer estimates the thickness of the Tertiary beds in the Apsheron Peninsula at 4,500 meters, the thickness of the Cretaceous beds at the southeast end of the Main Range at approximately 3,000 meters and the thickness of the Upper and the Middle Jurassic down to the Upper shales of the Main Range at 2,000 meters; consequently, the depth to the shales of the Main Range under the Apsheron Peninsula is about 10,000 meters. The thickness of the Lower Jurassic shales of the Main Range is not known, but it is not less than 2,000 meters.

This simple calculation shows that a heavy crystalline substratum underlies the Apsheron Peninsula at a depth not less than 12,000 meters. It should be mentioned that on the southwest border of this submergence appears a great rift which can be traced approximately 200 kilometers southeast of the city of Shemakha to the Neftechala oil fields, located at the estuary of Kura River. This line passes through the system of mud volcanoes of the Akhtarma-Pashaly, through the mud volcanoes of the Big and Little Kharami, through the Kurov-Dag, the oil field of Baba-Zanan (near the city of Salian on Kura River), the mud volcanoes of Douz-Dag, et cetera.

A little northeast of this line, approximately in the middle of the submerged zone, passes another great fault line, already mentioned,

merging near Shemakha with the first. Thence it can be traced along the left side of the Pirsagat River Valley to the sea somewhat south of the Aliat station on Cape Pirsagat. On this line there is also a whole chain of mud volcanoes along the so-called Aliat Ridge. On its southeastern prolongation is Hog Island, also a mud volcano, in the Caspian Sea not far from shore.

The aforementioned Nial-Dag Lagich rift, along which are outcrops of volcanic andesites and basalts, probably is the continuation of the faults northwest of Shemakha.

We have seen that, according to some authors, the Apsheron Peninsula can not be regarded as the prolongation of the Main Caucasian Range, for the additional reason that, with respect to the facies of its Tertiary formations, it approaches, rather, the southern forelands of the Main Range, that is, the region designated as the Kura plate.

As will be seen from the following discussion, the Lower Tertiary Apsheron series do not differ, in general, in their lithologic character, from the Flysch series of the Main Range, but sharply differ in this respect from the series of the same age in the Kura depression. The Paleogene beds of the region near Sumgait, represented by the Kown, Sumgait, Ilkhi-Dag, and Yunus-Dag series, both lithologically and faunally, differ from the Paleogene formations of the Kura "plate," which are represented by nummulitic sandstones, intercalated volcanic tuffs, and breccia of some older formation. There is no such facies on the Apsheron.

The Miocene series on the Apsheron Peninsula are developed in a special facies of diatom shaly clays with intercalations of extremely peculiar breccia. No such facies has yet been established in the Kura depression.

The diatom strata of Apsheron resemble the diatom beds of the Monterey series in California, not only in their lithologic character but also in their location at the base of the Fernando series, which is somewhat similar to the Productive series.

The Pliocene formations of the Apsheron—the Pontian stage, the Productive series, the Aktchagil, and the Apsheron series—are likewise not represented in the same way as in the Kura depression, although they have some points in common with the corresponding deposits of the latter.

It is not necessary to dwell on the analysis of other arguments in favor of the opinion that the Apsheron Peninsula forms a part of the Kura rigid plate. What has been stated suffices to indicate disagreement with this original, but very unconvincing, statement. Besides, further description of the tectonics of the Apsheron Peninsula and of

its composite series will show that it is in reality a prolongation of the Main Range, and is located in the zone of its submergence toward the southeast. This position which it occupies in the system of the Caucasian Mountains explains all the peculiarities of its tectonics and the lithologic character of its formations.

Let us now pass to the discussion of these peculiarities of the geological structure of the southeastern part of the Caucasian Range.

Stratigraphy of Southeastern Caucasus

The stratigraphy of this part of the Caucasus includes the Mesozoic (Jurassic and Cretaceous), the Tertiary, and the post-Tertiary formations.

JURASSIC

Jurassic deposits are developed in the zone of the Main Range. Their geological section, according to Bogdanovich, is as follows. The oldest series is massive black argillaceous shale with intercalated marls and sandstones and vegetable remains. The nature of the fauna of this series, known as the shales of the Main Range, is extremely vague. Its age is problematically determined as Lower Jurassic, and it is classified as a formation of the Lias stage. Above these strata lies the Khinalug series, represented by black and gray argillaceous shales with spheroidal concretions and vegetable remains. According to the fauna, this series is referred to the Bayotic-Bathonian stage of the Middle Jurassic.

The overlying series is composed of shaly clays passing into argillaceous shales and sandstones. It contains the Calloway fauna and is covered by formations of uncertain age, red and gray clays with intercalated gypsum. The Jurassic formations end with the massive limestone and dolomite beds of the Tithonian series. In the Jurassic section of this part of the Caucasus, there is a break, beginning with the upper strata of the Calloway and extending up to the Kimmeridgian inclusively, prior to the formation of massive Tithonian limestone and dolomite beds; that is, the Middle Jurassic transgressive movements were followed by regressive movements of the Upper Jurassic and the time of this break was, for the eastern Caucasus, the epoch of the most vigorous orogenic movements.

CRETACEOUS

The complex of Cretaceous deposits begins with the lowest Neocomian horizons. Bogdanovich established a direct transition of the Tithonian limestone-dolomite beds into the limestones of the Lower

Neocomian, composing the northern slopes of Mount Shah-Dag and several peaks on the southeast. Some of the later authors include the Neocomian limestones in the Tithonian series and begin the Lower Cretaceous formations with the so-called Khaltan series.

This series, whose age is determined as Hauterivian-Valanginian, is generally represented by more or less compact calcareous sandstones passing in places into small conglomerates, and by breccia-like limestones passing into block conglomerates. In general this series has a distinctly Flysch character and in its upper part passes gradually into laminated clays of Barremian-Aptian age.

As part of this series, Bogdanovich separated the *Philoceras* and the *Terebratulina* horizons, whose age he determined as Cenomanian.

Above these horizons lie beds of reddish brown marly clay, intercalated sandstone, and conglomerate. At the base are block conglomerates. The age of these beds is estimated as Upper Aptian. This formation was named by Bogdanovich the *Actinocomax* series on account of the occurrence of *Actinocomasplenus* Blain, mut. *caucasicus* Bogd and other *Actinocomax*. Its age was determined as Turonian-Senonian. Later investigators are inclined to lower its age to the Upper Aptian.

Above the red Upper Aptian beds lies a thick (not less than 1,000 meters) formation which Bogdanovich named Orbitoidal series. It consists of white marls, marly fucoidal and hieroglyphic sandstones, and breccia-like limestones. There are also greenish and reddish fucoidal clays which appear as a constant, though secondary member of this series. Lower horizons are dark clays interbedded with compact calcareous sandstones and breccia-like limestones. *Orbitoides* and *Lithothamnium* are commonly found in all the horizons. At the base of the Orbitoidal series, block conglomerates characteristic of the lower horizons are found. Bogdanovich determines the age of the Orbitoidal series as Maestrichtian Upper Cretaceous. This formation is most fully developed in the Dibrara series.

The writer found the Orbitoidal block conglomerates in the northwestern part of the Apsheron Peninsula and traced them southeast to Sumgait River, where they are submerged and covered by the Lower Tertiary deposits. Bogdanovich came to realize that this complicated series could hardly be regarded as one stratigraphic unit. He had, however, at that time no data for its subdivision. Later investigators divide it into several series, ascribing to them independent stratigraphic importance, thus, from the bottom up: the sub-Kemchian series, Cenomanian in age; the Kemchian series, of the Coniacian stage; the Red-colored series of the Dibrara, belonging to the Seno-

nian age; and the Orbitoidal series, in the strict meaning of this word, referred to the Maestrichtian horizon. All these stratigraphic relations are still in need of thorough verification.

The stratigraphic relations of the Mesozoic formations are shown in Table I.

In the southeastern Caucasus the orogenic phases of Cretaceous age occurred in the interval between the Upper Aptian and the Lower Cenomanian. The base of these formations, as we have seen, consists of huge block conglomerates. This orogenic phase is common to the entire Caucasus and coincides with the Austrian phase.

Evidences of separate movements were observed at the contact of Aptian-Berremian and Upper Aptian age (conglomerates at the base of the red Aptian beds), as well as during the deposition of the Kemchian series and of the Orbitoidal strata, in which huge block conglomerates and breccia-like limestone are found.

Mesozoic beds are developed principally in the region of the Main Range, where they form the highest peaks of this part of the Caucasus, as Shah-Dag and Shalbuz-Dag. They form also the walls of deep canyons cutting across the flanks of these giants, and the banks of mountain rivers flowing to the Caspian Sea.

TERTIARY

The Tertiary deposits, on the other hand, form the whole Apsheron Peninsula and the entire region of the Kabristan Steppes, together with the Saliani, or the Kura Steppes, bordering it on the south.

The working out of the geological section of Tertiary formations has required many years. Only a generalized scheme of this section is given here, since each district of this vast region, both stratigraphically and tectonically, has its own geological characteristics. Even within the limits of the same formation we must have several typical cross sections as well as sections of separate parts of the bed. This procedure is necessitated by extreme lithologic variation.

EOCENE

The complex of Tertiary deposits begins with the Flysch series of the Eocene. There are three such series: Yunus-Dag, Ilkhi-Dag, and Sumgait. These series occur only in the southeastern part of Caucasus.

The Yunus-Dag series represents interbedded strata of red-brown and light gray fucoidal clays and marls with thin gray glauconitic sandstones. It contains layers of breccia-like sandstones and limestones with fragments of *Inoceramus*, needles of sea urchins, and parts of crinoids. In the thin sandstones are found siliceous sponge

TABLE I

GENERALIZED SECTION OF TERTIARY AND MESOZOIC FORMATIONS OF SOUTHEASTERN CAUCASUS

After Golubiatnikov and Goubkin

Era	Period (Epoch)	Epoch (or Series)		Stage	Formation	Thickness in Meters	Lithologic Characteristics	Paleontologic Characteristics
CENOZOIC	QUATERNARY		Recent		Alluvial and eolian deposits Material ejected by mud volcanoes Lake deposits Alluvium Diluvium		Loess and silt-like clays and sands Mud breccia and fragments of various rocks Silt, sand, salt Gravel, sand, shingle, clays, etc. Clay, sand, fragments of various rocks	Helix sp.
			Recent		Recent deposits of Caspian rising above sea-level from 9.5 to 14 meters	10	Sand, clay, broken shells	*Cardium edule* Lin., *Didacna trigonoids* Pall., *Monodacna caspia* Eichw., *Adacna laeviuscula*, *Dreisssnsia polymorpha* Pall., etc.
			Ancient Caspian Deposits		Upper stage Terrace rising 8.5, 17, 26, 35 meters above the level of Caspian sea	34	Conglomerates, pebbles, broken shells, sands, sandy clays, etc.	*Didacna trigonoids* Pall., *D. piramidatum* Grimm, *Monodacna caspia* Eichw., *Adacna plicata* Eichw., *Dreissensia polymorpha* Pall., *Neritina liturata* Eichw.
					Middle stage Terraces reaching from 24 to 161 meters in absolute elevation	32 Break	Conglomerates, pebbles Limestone, shell limestone with pebbles, sands, sandy clays	*Didacna crassa* Eichw., *D. praetrigonoides* Nal., *D. surakhanica* Andr., *D. baeri* Grimm, *Dreissensia pontocaspia* Andr.
					Lower stage Baku stage	60	Conglomerates, sands, sandstone, sandy clays, shell limestone, and limestone	*Didacna catillus* Eichw., *D. rudis* Nal., *D. parvula* Nal., *D. carditoides* Andr., *Dreissensia polymorpha* Pall., etc.
					Sharp Unconformity. Break			
	TERTIARY	PLIOCENE	Upper Pliocene	Apsheron Stage 590 Meters	Upper	180	Limestones, sands, shelly clays, shell limestone, pebbles	*Monodacna Isseli* Andr., *M. bacuana* Andr., rare *Apsheronia propinqua* Andr., *Didacna intermedia* Eichw., etc.
					Middle	170	Sands, sandy limestones, calcareous sandstones, marls, clays	*Apsheronia propinqua* Eichw., various *Monodacna*, *Didacna intermedia*, *D. anisoconcha*
					Lower	240	Sands, shells, clays, below dark clays, interbedded with volcanic ash, gas-bearing sands at Bibi-Eibat, at Surakhany	*Apsheronia raricostata* Sjögr., *Limnaeus velutinus* Desh., *Dreissensia*, *Ostracoda*, etc.
				Clay with *Limnaea*		138	Clay with interbedded marl	*Limnaeus velutinus* Desh., many *Ostracoda*
			Upper	Aktchagil stage		38–60	Black clays, shaly calcareous clays, clayey shales, sands, volcanic ash, marls, limestones. Petroliferous sands at center of Surakhany	*Mactra subcaspia* Andr., *Cardium dombria* Andr. *C. vogti* Andr., *Ostracoda*, *Foraminifera*, many fish remains
				Productive Series 1,374–1,400 Meters	Upper division	644–826	Clays, sandy clays, sands, clayey sands, lenticular sandstone intercalations. Petroliferous at Bibi-Eibat, Surakhany, Balakhany, Sabunchi-Ramany district, Puta, Lok-Batan	*Unio yassamalica* Golub., *Planorbis*, *Limnaeus*, *Melania* sp., *Ancylus* sp., *Hydrobia* sp., *Cytheretorosa* Jones, *Iliocypris* sp., *Limnocythere* sp., etc., *Ostracoda*, *Oogonia*, *Characea*, *Chara escheri* Braun, *Chara voltzii* Braun, etc.
					Middle division Continental deposits	154–243	Coarse-grained sands with small angular pebbles and fragments of rocks and lumps of clay, lenses of sandstone. Petroliferous at Binagady, Mt. Atashkya, and Balakhany	In Cretaceous and Tertiary gravel are: *Anthozoa*, *Echinoidea*, *Inoceramus*, *Rinchonella*, *Mactra*, *Cryptomactra*, *Spaniodontella*, *Dreissensia*, and *Cardidae* of Pontian sands. *Helix* (rarely)
					Lower division	219–394	Sands, sandy clays, sandstones. Petroliferous areas: Balakhany-Sabunchi-Ramany, Bibi-Eibat, Surakhany, Binagady, Sula-Tepe, Lok-Batan, Puta, Atashkya, etc.	Fragments of *Planorbis*
					Sharp Unconformity. Break. East Caucasian Orogenic Phase			

						Pontian Stage	Upper (Babajan) horizon	50	Dark gray clays, siliceous marl, lenses of detrital limestone	*Monodacna babadjanica, Didacna lascarevi* Andr., *D. schemachinica, D. pirsagalica*, etc., *Prosodacna ampelakiensis, Melonopsis lörentheyh* Andr.
							Middle horizon	33	Dark gray clays, striped clays, interbedded with siliceous marls	*Valenciennesia annulata, Cardidae, Ostracoda*, fish remains, etc.
							Lower horizon	216	Dark gray shaly clays with rust-colored intercalations	Small *Cardidae* and sharp-ribbed *Limnocardium* sp.
						Sharp Unconformity. Break. East Caucasian Orogenic Phase				
						Diatom Beds	Analogous to Maeotic and to Upper Sarmatian beds	136	Thin bedded clays with siliceous concretions, siliceous breccia, white, light gray laminated clays crowded with siliceous shells of diatoms. Petroliferous at Binagady	At Kabristan, typical Maeotic fauna: *Congeria panticapaea, Venerupis abichi, Modiola volhynica*, etc.; Upper Sarmatian fauna: *Mactra caspia*. At Apsheron Peninsula: diatoms, *Cocconeis scatellum* Ehr., *Coscinodiscus* sp., *Aulacodiscus* sp., *Mastogloria smithii* Tv., *Achlynoptychus nonnarius* Ehr., and many others
							Middle Sarmatian Beds with *Cryptomactra pesanseris* Myer	20	Clay interbedded with siliceous marls	*Cryptomactra pesanseris, Trochus, Modiola* cf. *marginata, Cardium* cf. *obsoletum, Mactra* cf. *fabreana*.
							Analogous to Lower Sarmatian	250	Same	Tubular sea weeds thickly covered by embryonic *Pelecypoda (Pectenariopsis)*
							Spaniodontella beds (The Karagan horizon)	?	Dark gray shaly clays interbedded with siliceous marls	At Apsheron, small *Pelecypoda* resembling *Spaniodontella;* at Kabristan, usual *Spaniodontella* of north Caucasian type
						II Mediterranean Stage	*Spirialis* beds Chokrak-*Spirialis* beds of Kabristan	65 500	Dark gray shaly clays, siliceous marls, siliceous dolomitic limestones as big breccia blocks. Petroliferous sands at Cheil-Dag (Kabristan Steppes)	*Spirialis hospis* Kittl (everywhere); fish remains. At Kabristan, Chokrak fauna: *Venus, Arca, Ervilia, Bulla, Trochus, Cerithium, Balanus*, etc., fish remains
						Maikop Series	Upper horizon	200	Laminated chocolate-brown clays with yellow ochreous formations	Fish remains, *Meletta* sp.
							Lower horizon	130	Thin alternating layers of chocolate-brown clays and greenish gray shaly clays. Intercalations of yellowish brown marl. Bituminous in places	Fish remains: *Amphasyle* cf. *heinrichi* Heckel, *Meletta* sp., *Merluscius* sp., *Lepidopus*, etc.
						Kown Series	Green Kown		Green shaly clays interbedded with sandstone, intercalations of fine detrital sandstone some merging into reddish brown shaly clays interbedded with sandstone intercalations of "Gliabi"	Finest fragments of bivalves
							Brown Kown		Laminated brownish black clays with yellow ochreous formations. Intercalations of combustible bituminous shales	Fish remains, *Zeuglodon? Radiolaria*
							White Kown	600	White and greenish light gray marls and marly clays interbedded with green friable sandstones Local indications of petroleum throughout series	Plentiful *Foraminifera, Orbulina*, and *Globigerina*
						Flysch Formations	Sumgait Series	Upper horizon		Reddish brown clays with thin beds of light gray and white friable sandstone. Manganese biscuit-shaped concretions	
								Lower horizon	100	Reddish brown clays interbedded with fucoidal white marls and gray glauconitic sandstones	*Fucoides, Foraminifera, Frondicularia, Nodosaria*, etc.
							Ilkhidag Series	Upper horizon		Dark gray greenish clays non-reacting with HCl; intercalations of grayish brown coarse sandstone	*Foraminfera* and spicula of sponges
								Lower horizon	300	"Treskunovy" rocks, dark gray clays and marls with intercalations of grayish brown coarse and slab sandstones	*Fucoides* *Foraminifera* *Orthofragmina?*
							Yunus-Dag series (red colored)		200	Reddish brown and light gray fucoidal clays and marls interbedded wit' thin scaly glauconitic sandstones, intercalations of breccia limestones and sandstones	Remains of large *Inoceramus*, needles of sea urchins, crinoids in thin sandstones, sponge spicules and *Foraminifera (Rotalidae* and *Discorbina)*

CENOZOIC — TERTIARY — PLIOCENE (Middle, Lower) — MIOCENE (Upper, Middle) — OLIGOCENE (Lower) — EOCENE

Pope, Lok-Batan, Puta, Atashkya, etc.

Break. Laramic Orogenic Phase

MESOZOIC	CRETACEOUS	Upper Cretaceous	Orbitoidal Series of Maestrichtian Stage (After Bogdanovich)	Maestrichtian	Orbitoidal series (Horizon I^e after Bogdanovich)	550–600	White marls, marly hieroglyphic sandstones, breccial limestones	*Fucoides. Foraminifera: Lepidorbitoides* (*Orbitoides*) *socialis* Lym., *Orbitella apiculata* Shlumb., *Calcarina*, etc. *Ostrea* sp., *Inoceramus* sp., *Belemnitella mucronata*
				Santonian-Campanian	Red Dibrar series. (Horizon I^b after Bogdanovich). "Yunus-Dag series" of some Baku geologists	450	Greenish and reddish marls and clays. White marls, breccial limestones passing into conglomerates	Numerous remains of large *Inoceramus*. Bogdanovich indicates common occurrences of *Orbitoides*
				Coniacian	Kemchi series (After the Baku geologists) Horizon I^a after Bogdanovich	200–250	Calcareous sandstones, breccial limestones, white marls, microconglomerates, dark gray clays	*Inoceramus subquadratus* Schlüter, *Ostrea* cf. *incurvata* Nelsi. Numerous *Orbitoides* after Bogdanovich
				Cenomanian	Subkemchi series (After some Baku geologists). Horizon I^a after Bogdanovich	400–450	Brown and gray clays, curved beds of sandstone, gray marls, block conglomerates at base	Absence of fauna
		Lower Cretaceous	Tigonian-Aptian (Bogdanovich)	Aptian	Red colored series (*Actinocamax* horizon after Bogdanovich)	450–500	Reddish brown marly clays, intercalations of sandstone, conglomerates, block conglomerates at base	*Belemnites, Neohibolites ewaldi* Strome, *N. aptiensis* Stoll, *Belemnitis semicunaliculatus* Blain, small *Pelecypoda*, *Ostrea*, fragments of *Inoceramus*
			Cenomanian (Bogdanovich)	Barremian	*Terebratulina* horizon		Gray and greenish gray laminated clays with intercalations of gray marls, and marly hieroglyphic sandstones. Cliffs of coral limestones	*Terebratulina rigida* Sow., *Exogyra canaliculata* Sow. and E. cf. *sigmoidea* Reus, *Trochus* aff. *Buneli* d'Arch., *Turritellea* sp., *Cidadis vesiculosa* Goldf., etc.
					Phylloceras horizon	500–600	Lithologically difficult to distinguish from *terebratulina* strata	*Phylloceras forbesianum* d'Orb., *Caudryceras* aff. *Odiense* Kossm, etc.
			Titonian-Neocomian (Bogdanovich)	Valanginian-Hauterivian	Khaltan series	?	Compact calcareous sandstones passing into small conglomerates, intercalations of limestone; series has Flysch character	In sandstones, *Foraminifera: Globigerina, Nodosaria, Textularia*, etc., small *Belemnites*, typical Middle and Lower Neocomian
	JURASSIC	Upper		Titonian	Shah-Dag limestones	?	Massive beds of dolomites and limestone	Corals, oysters, large *Nerinea* and *Lythoceras*
		Middle	?			?	Red and gray clays with gypsum	
			Calloway		Khinalug series		Argillaceous shales, sandstones, shaly clays	Calloway fauna
			Bathonian			1,370	Black argillaceous shales with siderite and Tutenstein. Sandstones, some calcareous	Plant remains, Middle Jurassic fauna of Bathonian-Bajocian age
			Bajocian					
		Lower	Lias		Shale beds of Main Range	?	Black argillaceous shales, marly sandstones with interbedded gypsum and plant remains. Cleavage in shales	Fragments of *Belemnitella;* plant imprints

spicules and *Foraminifera* (*Rotalidae* and *Discorbina*). In the field, this series is often mistaken for the red Dibrara series because of their great lithologic resemblance. The latter, accordingly, is often incorrectly called "Yunus-Dag," thus causing confusion in establishing the stratigraphy of northern Kabristan.

The Ilkhi-Dag series, which covers the Yunus-Dag, consists of two horizons. The lower horizon is composed of thick beds of dark gray marly clays and marls with thick intercalations of gray-brown coarse-grained sandstone and thin slab sandstones. The upper horizon, which lies directly under the multi-colored formations of the Sumgait series, consists of dark gray shaly clays with thin intercalations of black combustible shales with fish remains and intercalations of gray friable sandstone.

The lower horizon is characterized by the *Foraminifera: Nodosaria*, *Cristellaria*, *Pullenia*, *Operculina*, *Rotalia*, and, very rarely, apparently in the secondary deposits, *Lepidorbitoides* (*Orbitoides*) *socialis* Leym. In the sandstones of the upper formations are also found foraminifers and sponge spicules.

Later investigators combined the Ilkhi-Dag, the Yunus-Dag, and the Orbitoidal series of the Upper Cretaceous into one series. This series was called Ilkhi-Dag, or Orbitoidal, and the age of the combined series were determined as Maestrichtian and Danian. By this procedure the whole overlying Tertiary horizon was mechanically lowered in age. The mistake was made because the Yunus-Dag series, which the writer established in the northwestern part of the Apsheron Peninsula, and which contains fragments of Cretaceous fauna in its secondary deposits, was confused with the red formations of the upper Dibrara beds, which actually do contain Upper Cretaceous fauna, as established by Bogdanovich 30 years ago.

The Sumgait series in its lower part is composed of interbedded red-brown clays, white fucoidal marls, and gray cross-bedded glauconitic sandstones. In its upper part are red-brown clays with manganous biscuit-shaped concretions.

OLIGOCENE

The Oligocene, in its lower part, is represented by series which, according to their lithologic character and the conditions of their formation, resemble the typical Eocene and Upper Cretaceous Flysch series. Two series are recognized: the Kown and the Maikop series.

The Kown series, which includes beds of the Lower Oligocene, is subdivided lithologically into three horizons: the lower or White Kown, the middle or Brown Kown, and upper or Green Kown.

The White Kown is composed of white, light gray, and greenish marls and marly clays with intercalated friable sandstones with numerous *Foraminifera: Orbulina* and *Globigerina*.

The Brown Kown consists of dark brown laminated clays with abundant inclusions of yarozite. It contains intercalations of combustible bituminous shales. Both the clays and the shales are crowded with fish remains. In places, remains of whale-like animals are found (*Zeuglodon?*).

The Green Kown forms thick beds of green shaly clays with intercalated white siliceous and grayish brown cross-bedded sandstones and fine-grained sandstone with minute fragments of ostracods and foraminifers.

In the northwestern part of the Caucasus, in the Anapa region, the foraminiferal strata, which according to their stratigraphic position correspond with the Kown series of the Apsheron Peninsula, contain light, porous siliceous clays, compact siliceous sandstones, and streaked intercalations of almost pure silica. They resemble in this respect the Menelitic shale series of the northeastern Carpathian slope. They lie at the same stratigraphic level with that series and belong to the Lower Oligocene.

OLIGOCENE-MIOCENE

The Maikop series presents a remarkably consistent and permanent geological complex, which is distributed throughout the Caucasus at a definite stratigraphic level and serves, therefore, as a very convenient key horizon. Its age corresponds with the Lower Miocene and Upper Oligocene. At present there are attempts to lower its age, to make it correspond with the entire Oligocene. This would lower the age of the aforementioned Kown series, to which there is a tendency to attribute, together with the Sumgait series, an Eocene age. If there may be a possibility of disputing the lower limits of the Maikop series, there is no doubt as to its upper limits, since the Maikop series almost throughout the whole of the Caucasus contains the fauna characteristic of the Middle Miocene.

Lithologically this remarkable series is composed of laminated chocolate-brown clays with yellow ocher formations. It contains numerous fish remains, *Meletta* scales and entire specimens of *Amphisyle* cf. *Heinrichi*, for which it was named "Amphisylous clays" by the eminent geologist D. V. Golubiatnikov.

In the upper strata petrified trunks of *Cedroxylon* are commonly found. Formations of the Maikop series are bituminous and in some places are regarded as the mother beds of many oil-bearing districts, including the Baku oil fields.

This completes the description of the section through the Lower Tertiary formations of the southeastern Caucasus, which present an uninterrupted series in this region. Orogenic movements took place between the Upper Cretaceous and the Tertiary ages. The presence in the Yunus-Dag series of breccia-like limestones and sandstones containing fragments of the Upper Cretaceous fauna serves to prove this contention. Fragments of *Inoceramus*, parts of crinoids, needles of sea-urchins, et cetera, are evidence of the fact that at the time when this series was formed, the Upper Cretaceous near by was dry land which was being subjected to erosion.

This phase apparently corresponds with Laramic. It has been found also in the northern and northwestern Caucasus and in several other places.

MIOCENE

The whole Miocene is completely represented by three series: the upper half of the Maikop series already mentioned, the *Spirialis* strata, and the Diatom series.

The *Spirialis* strata, because of their stratigraphic position, belong to the Middle Miocene—to be exact, to the second Mediterranean stage, characterized by greenish gray or greenish brown clays with intercalations and concretions of dark gray siliceous marls. All strata contain numerous *Spirialis*, from which the whole series received its name. This series is also constant and characteristic throughout the Caucasus. *Spirialis* strata represent an argillaceous and a deep-water facies of the second Mediterranean stage.

The limestone and the sandy clay facies of this stage contain abundant and varied fauna described by the late Academician Andrusov under the name of the Chokrak stage. In the southeastern Caucasus, namely, central Kabristan, deposits of this stage are more generally of the shallow-water type. In such cases also, instead of *Spirialis*, representatives of the Chokrak fauna are found.

The Diatom strata embrace the whole Upper Miocene and the upper part of the Middle Miocene. They correspond with the *Spaniodontella* (Karagan) horizon related to the second Mediterranean stage, and, together with the *Spirialis* strata, correspond with the Sarmatian and Maeotic stages of the Caucasian Miocene. They are light, grayish and white laminated clays and shales crowded with siliceous remains of diatom seaweeds; dark gray shaly clays containing numerous fish remains; and siliceous breccia. In the deep-water facies no other fossils except the diatoms and fish remains are found, but where the deposits are of shallow-water character, as in Kabristan, a molluscan facies is found. At present the Diatom series is sub-

divided into horizons characterized by their fauna and almost entirely corresponding with the same horizon of the Miocene deposits in the northern Caucasus. This series is divided into strata containing *Spaniodontella*, strata of Sarmatian stage, namely, the Middle Sarmatian (with *Mactra pesanseris*), the Upper Sarmatian (with *Mactra caspia*), and the formations of the Maeotic stage. On the Apsheron Peninsula this series is developed in deep-water facies as diatom strata, considered by some geologists to be one of the oil-producing complexes similar to the Maikop series.

In studying the lithologic character of Miocene formations and their position in the Apsheron Peninsula, we get the impression that here, through the entire Miocene age, deposits principally of a clay character have been forming uninterruptedly. The orogenic movements in the regions around the Caucasus affected somewhat the character of deposits (siliceous breccia). In the vicinity of the Kabristan Steppes, especially in the northern Kabristan, breaks and angular unconformities are found between the Maeotic layers and the Middle Sarmatian, corresponding with the Attic orogenic phase.

In some parts of northern Kabristan, for example, between the villages of Dusdar and Angel, east of the village of Hilmil, the Pontian strata are superimposed unconformably upon the series of the Upper and Lower Cretaceous (orbitoidal strata of the Maestrichtian horizon and the *Terebratula* strata of the Aptian-Barremian stage). According to Professor Bogachev, marly clays containing Pontian fauna (*Prosodacna*, *Didacna*, *Dreissensia*) were found by him on the northern slope of Shah-Dag at the elevation of 2,343 meters on an eroded surface of faulted Middle Sarmatian limestones, which in their turn were resting on Eocene limestones with *Trigonia* fauna.

It must be noted that in northern and central Kabristan a sharp unconformity is found between the Maeotic and Pontian stages, due to the orogenic movement which took place here at the end of the Miocene, but which, nevertheless, did not interrupt the depositional processes throughout the Apsheron Peninsula.

PLIOCENE

Pliocene formations in the described region consist of: (1) Pontian stage, (2) Productive series, (3) Aktchagil series, and (4) Apsheron stage.

Pontian stage.—The Pontian stage was discovered at the beginning of this century by Academician Andrusov in the Shemakha district where it is fully developed and corresponds with the Pontian strata of the Black Sea basin around the Kerch and Taman penin-

sulas and in the northwestern part of the Caucasus. Nevertheless, its stratigraphic position among the Tertiary deposits of the southeastern Caucasus became ambiguous after it had been proved that Aktchagil,

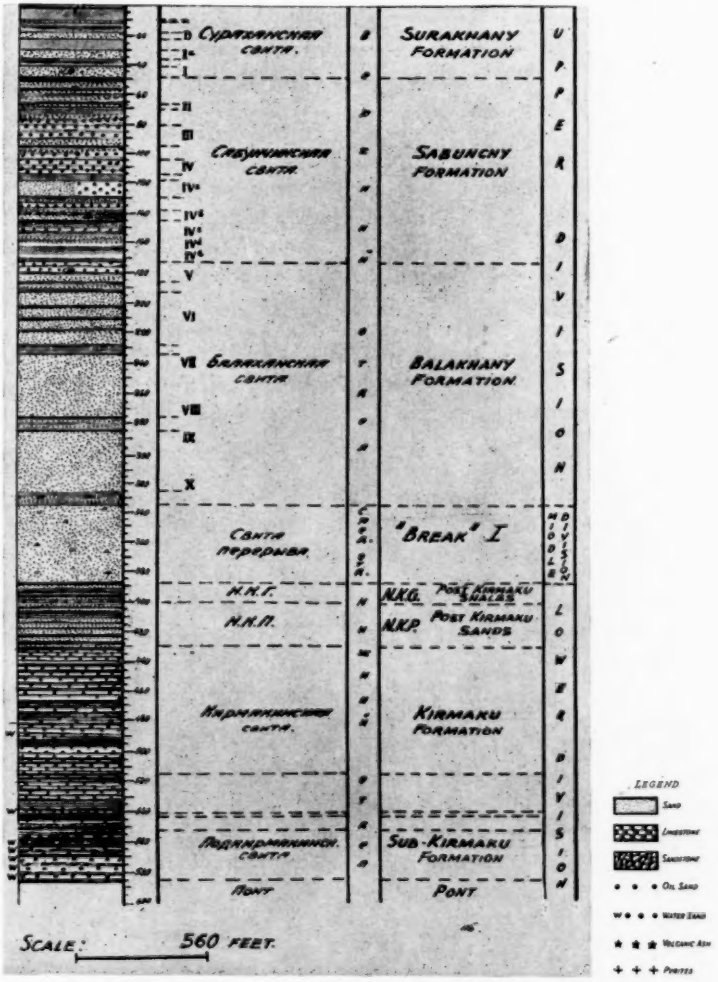

FIG. 2.—Stratigraphic section in central part of Lenin district (Balakhany-Surakhany-Ramany oil fields). By A. I. Krems. Legend for this section also applies to following columnar sections.

which was considered analogous to Maeotic, was Pliocene in age, and that it was not older, but much more recent than Pontian. It became necessary, therefore, to re-examine all the established age correlations. The final deciphering of the stratigraphy of the Pliocene formations was made in 1913, when Pontian beds, containing *Valenciennesia annulata* Rouss, were found by the writer on the Sumgait planchette, and by D. V. Golubiatnikov in the Binagady oil field at the base of the so-called Productive series.

Later the writer located in several places at the base of the same Productive series the upper horizons of Shemakha Pontian, containing fauna of the so-called Badadjan strata. Only after this did the stratigraphic position of the Productive series become clearer. This series had been wandering all over the section of Tertiary deposits from top to bottom and back, beginning with the Oligocene, where it was placed by the earlier investigators (Simonovich and Sorokin, 1888; Shegren, 1891). Thus it became possible to construct a correct stratigraphic scheme and to put a solid foundation under the tectonics of the Apsheron Peninsula and the adjacent regions.

The Pontian stage is divided into three horizons: the Lower, the Middle, and the Upper.

The Lower horizon is represented by dark gray shaly clays with small rare-ribbed *Cardium* and with *Limnocardium* sp.

The Middle horizon consists of dark gray striated clays with intercalations of siliceous marls; in these strata are found *Valenciennesia annulata*, *Cardidae*, *Ostracoda*, and fish remains.

The Upper horizon is characterized by dark gray and rusty brown clays with intercalations of siliceous marls and lenses of detrital limestone. This layer contains abundant Badadjan limestone fauna in which the presence of *Prosodacha ampelakiensis* and *Melanopsis lorentheyi* is worthy of special attention. Their presence raises the upper limits of the Black Sea Pontian and allows the Badadjan horizon to be regarded as analogous to the lower half of the Kimmerian stage (Middle Pliocene) of the Black Sea basin.

Productive series.—The Productive series of the Apsheron Peninsula was so named because it contains tremendous oil accumulations within the Apsheron Peninsula as well as in the adjacent regions on both shores of the Caspian Sea. Its age is referred to the lower part of the Upper Pliocene and partly to the Middle Pliocene (within the limits of Apsheron, where it conformably overlies the Pontian). Its thickness is 1,400–1,500 meters. It contains more than 16 distinct oil-bearing horizons, each consisting of several oil-bearing strata.

A long, thorough study of this series, at its natural exposures,

and the study of the numerous oil-well data, enabled D. V. Golubiatnikov and his followers to elaborate a most exact subdivision of this series into separate horizons and into strata with exact lithologic and faunal characteristics. On this basis has been developed a special

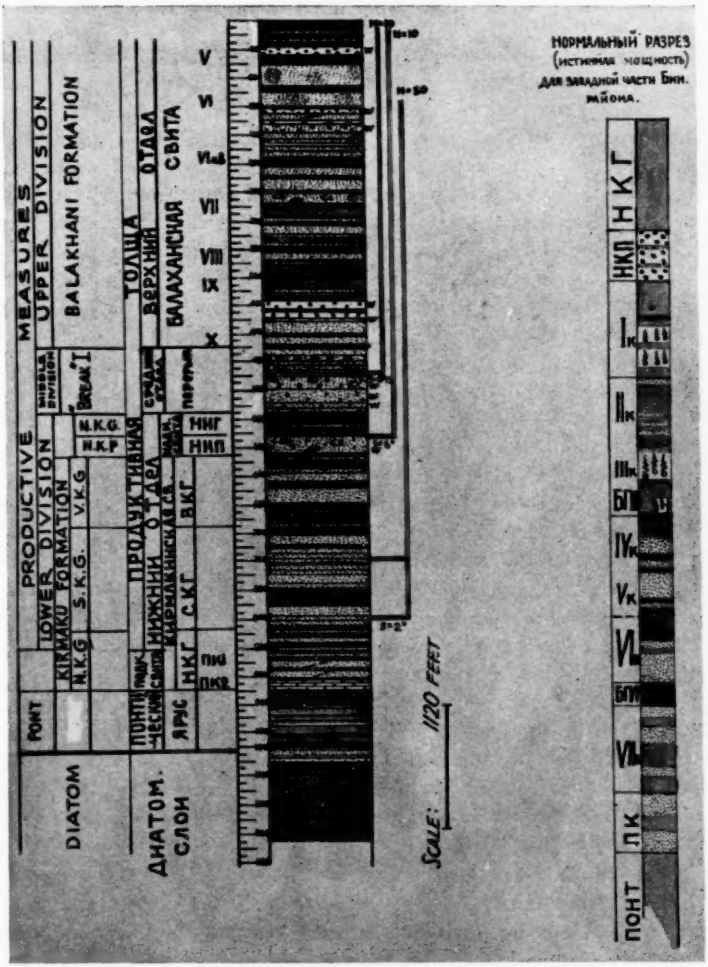

FIG. 3.—Stratigraphic section of Binagady oil field.
By A. I. Mesropian.

branch of industrial oil geology which makes possible the scientific direction of the exploitation of oil fields. On the basis of these extensive data it became possible to solve the problem of determining the conditions under which this series was formed.

D. N. Golubiatnikov separates the Productive series into three divisions: the Upper, Middle, and Lower.

The Upper division is characterized by gray and brown calcareous clays, argillaceous sands, gray and brown sands, intercalations of sandstones, in places in the form of concretions. Its thickness is 820–830 meters. In its upper horizons it contains representatives of fresh-water fauna (*Unio, Planorbis, Lymnaeus, Melania,* et cetera; *Oogoniae; Characea: Chara escheri* Braun, *Chara voltzi* Braun, et cetera). This series is petroliferous at Bibi-Eibat, Surakhany, Kara-Chukhur, the Balakhany-Sabunchy-Ramany region, Kala, and Lok-Batan, but barren at Binagady, on Artem Island, Khurdalany, Puta, and in other places where it forms the remote parts of folds in the center of which are outcroppings of Lower Tertiary beds.

The Middle division consists of continental formations: coarse-grained sands, containing small angular pebbles and rubble-like rock fragments, rounded lumps of clay, with intercalations of sandstones and very thin intercalations of clay.

The thickness of the series is 240–250 meters. It is petroliferous at Binagady, Balakhany, Mount Atashka, and Lok-Batan, where was completed at the end of May, 1933, one of the most splendid oil gushers at a depth of 547 meters. Such a gusher in Baku has not been seen for the last 30 years. There is practically no fauna present in these strata and only in a few places is *Helix* found in the sands. The lower part of this series is named the "First Break" and is represented by conglomeratic rough-grained sands.

The Lower division consists of sands, arenaceous clays, and sandstones. In the clays, fragments of *Planorbis* are found in a few places. This series is about 400 meters thick and is oil-bearing at Puta, Mount Atashka, Sulu-Tepe, Khurdalany, Baladjary, Binagady, on Artem Island, and at Bibi-Eibat. At present its most productive area is in the Balakhany-Sabunchy-Ramany region.

Each of these divisions is subdivided into several series. The Upper division, from the top down, contains the following series: Surakhanian, Sabunchian, and Balakhanian. The Middle division, in the language of the oil-field workers, is called the "Break" series and includes water-bearing horizons. The Lower division is subdivided into four series: super-Kirmaku clays, super-Kirmaku sands, the Kirmaku

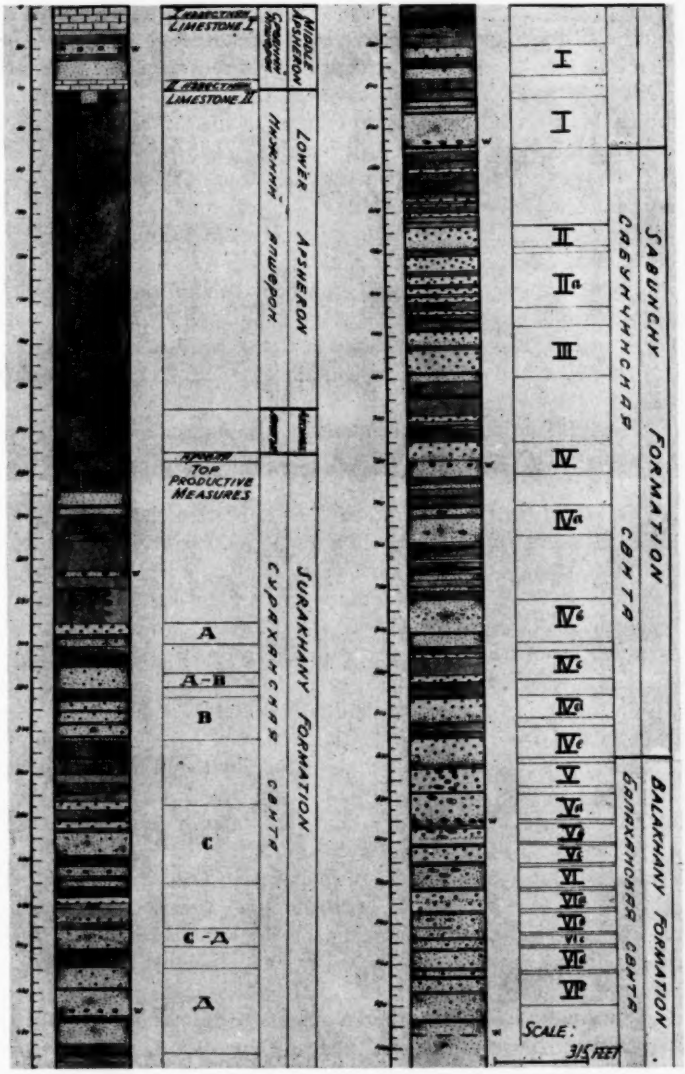

FIG. 4.—Stratigraphic section in Surakhany district.
By S. Shulgin and B. Kluchev.

series proper, and the sub-Kirmaku series. In each of these series definite oil-bearing horizons have been established.

Aktchagil stage.—The Aktchagil stage in several places covers the Productive series unconformably. Its thickness on the Apsheron Peninsula does not exceed 38–40 meters. In the Kabristan Steppes it increases to 100 meters, but still remains considerably less than the thickness of the Aktchagil beds in the northern Caucasus, where it is more than 400 meters.

The Aktchagil is represented by shaly calcareous clays, argillaceous shales, calcareous sandstones, and intercalations of flour-like white volcanic ash. On the Apsheron Peninsula, in the upper part of the Aktchagil strata, are beds of clays non-reacting with acids, which during drilling serve as a good key horizon. Sandstone intercalations at Bibi-Eibat and Surakhany contain gas and transparent water-colored light oil.

This Aktchagil stage is characterized by its usual fauna, presenting a mixture of marine forms (*Mactra subcaspia*, *Cardium dombra*, and *Potamides*), and semi-fresh-water forms (*Dreissensidae*, *Cassidulina crassa* d'Orb, *Truncatulina lobatula*, *Discorbina araucana*, and numerous fish remains). The habitat of the Aktchagil fauna is an open sea basin, strongly diluted by fresh water and approaching in type the present Azov Sea (Maeotic Sea of the ancient Greeks). For this reason Academician Andrusov considered the Aktchagil strata analogous to the Maeotic series of the Kerch Peninsula and referred it to the Upper Miocene age, and the Productive series to the Sarmatian stage. Presence in the strata of the Middle division of the Productive series of *Cardidae* and *Dreissensia* of Pontian type caused Andrusov himself to revise his former opinion, beginning thereby the general revision of the stratigraphy of Pliocene formations on the Apsheron Peninsula. Until 1929 the distribution of Aktchagil formations toward the west was known, approximately, only as far as the Mineralni Vodi (city of Mineral Waters) meridian in the northern Caucasus. In 1929 the writer found formations with characteristic Aktchagil fauna on the opposite extremity of the Caucasus, on the Taman Peninsula, in the upper part of the so-called Kuialnitzk stage, together with representatives of Kuialnitzk fauna.

Apsheron stage.—The Apsheron stage is the uppermost member of Pliocene formations in the southeastern Caucasus. At its base Golubiatnikov recognizes a special series of dark gray calcareous clays, containing *Lymnaea*, whereas the upper deposits he divides into three horizons: Upper, Middle, and Lower. The Lower horizon is represented by sands, shaly strata in the upper part, and clays with inter-

calations of white volcanic ash at the base. The Middle horizon consists of sands, sandy limestones, and gravel. The thickness of the

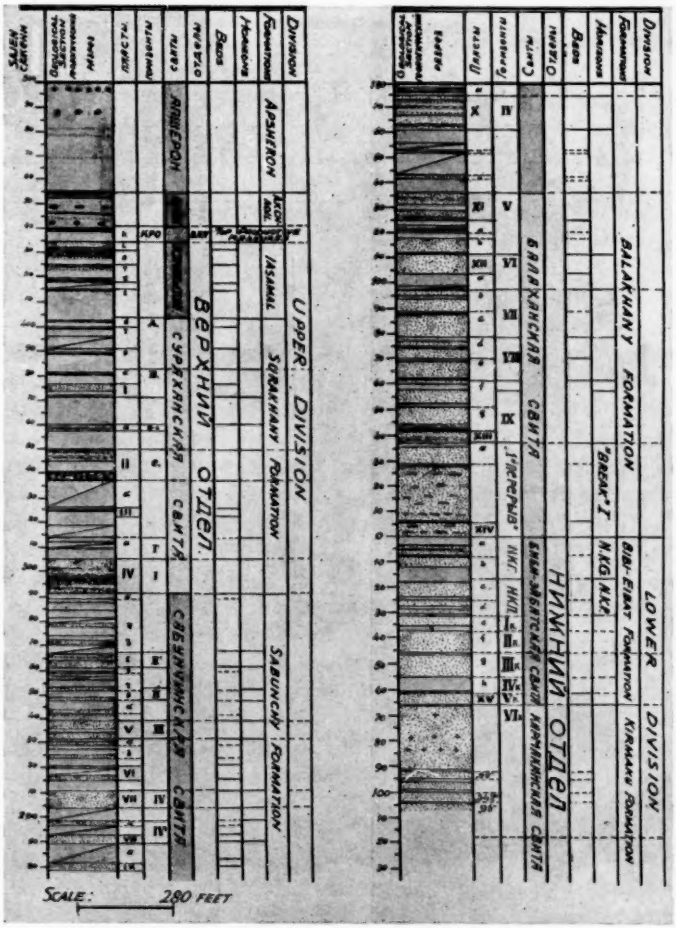

FIG. 5.—Stratigraphic section in Bibi-Eibat oil field.
By S. A. Kovalevsky.

Apsheron stage together with the *Lymnaea* clays is about 640 meters on the Apsheron Peninsula and more than 1,000 meters in the Kabristan Steppes.

The Apsheron fauna is characterized by a peculiar molluscan group which is also representative of the fauna of semi-fresh-water basins of the present Caspian Sea type. The most of the Caspian molluscs belong to the *Cardidae* family (*Didacna*, *Monodacna*, *Adacna*), and to the *Dreissensidae* family. Fauna of this composition reappeared several times in the course of the geological history of the Tertiary age. On these grounds Andrusov spoke of the Caspian fauna as of a typical semi-fresh-water basin fauna.

Beginning with the Lower Pliocene, he established four faunas of such type: Pontian, Apsheron, Kuialnik, and Kimmerian (fauna of the ore beds of the northwestern Caucasus). As a further development of these faunas after the Tertiary age, appeared the Baku stage fauna of the numerous terraces of the ancient Caspian, and finally the fauna of the present Caspian.

The Aktchagil fauna is the extreme form in the development of fauna of another type. It originates from the fauna of the second Mediterranean stage, represented in the Caucasian-Crimean region by the Chokrak fauna. This fauna was superseded by the Sarmatian stage fauna through several transitional types and later passed into the Maeotic fauna. The latter, it is true, has an admixture of forms which are not present in the Sarmatian and which are akin to the Chokrak fauna, but it also contains some fresh-water forms.

This Maeotic fauna, as the writer has proved elsewhere, was the one from which the Aktchagil fauna originated. The latter approaches in character the modern fauna of the Azov Sea. Thus throughout the Pliocene a parallel development of two faunal types took place. At times these two types of fauna became mingled, as at the end of Kuialnitz age, when the Kuialnitz basin of the Caspian type was invaded by the Aktchagil fauna of "Maeotic" type.

The Pliocene ended with a sharp interruption of deposition at both ends of the Caucasian Range. In the northwest this change occurred somewhat earlier, immediately after the Aktchagil age, and at the southeast considerably later, that is, after deposition of the thick beds of the Apsheron stage. The latter, together with Aktchagil, formed a compact cover of impervious rocks for the oil-bearing strata which were being formed within the Productive series of the southeastern Caucasus.

At the northwestern end of the Caucasus a thick series of sandy and argillaceous strata, contemporary with the Productive series—the so-called "ore-covering beds"—remained without cover of impervious rocks. For this reason, large accumulations of oil could not occur there, such as occur on the Apsheron Peninsula. Here is the basis for

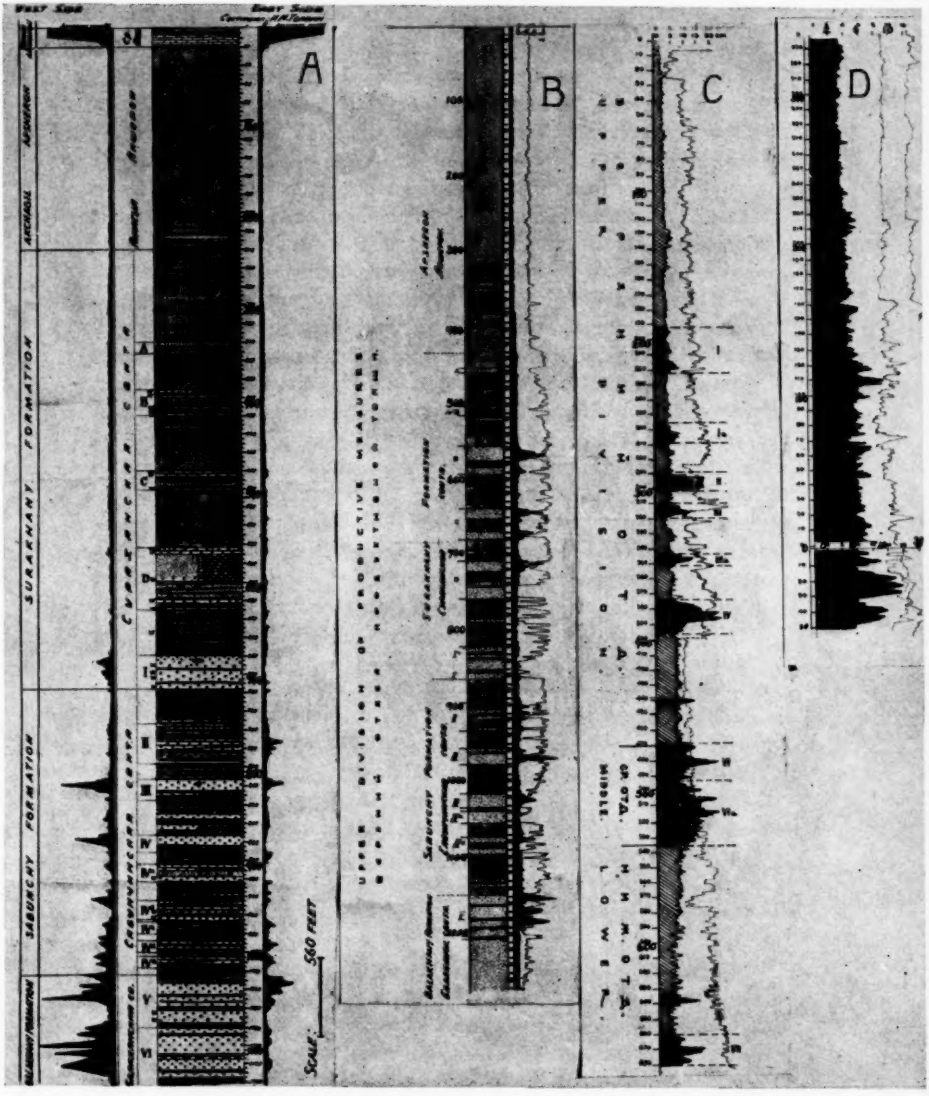

FIG. 6.—Stratigraphic and electrical resistivity sections.
A.—Kara-Chukhur oil field. By I. I. Tolbin.
B.—Kala oil field. By I. I. Tolbin.
C.—Lok-Batan oil field.
D.—Ker-Gez oil field.

estimating the industrial importance of the oil fields located at both ends of the Caucasus.

As regards the orogenic movements in the Pliocene age, we must note a considerable interruption of deposition between the Pontian and the Productive series. Blocks and whole cliffs of Pontian limestones observed in several places on the western Apsheron Peninsula (Kosmali-Dag) within the lower horizons of the Productive series, and commonly occurring fragments of Pontian fauna in conglomeratic sandstones of the Middle and Lower divisions of the same series—these facts prove beyond any doubt the existence of such a "break," which was evidently due to the development of a sharp organic phase between the Lower and the Middle Pliocene. This phase, which took place also in other parts of the eastern Caucasus, was named the "Eastern Caucasian" phase. In the Shemakha region this interruption lasted until the beginning of the Aktchagil transgression, that is, during the whole Middle Pliocene, and partly through the Upper Pliocene. The Pliocene ended with a sharp interruption of deposition after the Apsheron age. At the end of the Tertiary period, the main orogenic phase, corresponding with the Valakhian phase, took place. During this phase the entire complex of Tertiary deposits was subject to the most active orogenic movement, as the result of which arose all the basic tectonic forms of the southeastern Caucasus.

This phase continued a long time and into the Quaternary period.

QUATERNARY

The Quaternary period is divided into Ancient Caspian deposits and Recent formations. The Ancient Caspian deposits are subdivided into three stages: Lower, Middle, and Upper.

The Lower stage is also called the Baku stage. It is composed of sands, sandstones, conglomerates, sandy clays, limestones, and shaly strata. The principal fauna representatives of this stage are: *Didacna Catillus* Eichw., *D. rudis No. 1*, *D. parvula No. 1*, *D. carditoides* Andr., *Dreissensia pontocaspsica* Andr., and other fresh- and semi-fresh-water forms.

Some authors ascribe to the formations of the Baku stage the age of the Guentz glacial period, and others raise it to the level of the European Mindel glacial period. Within the limits of the region described, these strata as well as the underlying Tertiary formations are everywhere faulted. They are found up to 278 meters above the level of the Caspian Sea. After their deposition the aforementioned orogenic phase ended, and only epeirogenic movements took place. Traces of these are preserved in the form of numerous terraces left

by the ancient Caspian Sea, which had deposited beds of the Middle and Upper stages.

The Middle stage is represented in traces of five terraces which range in elevation from 23 to 106 meters above sea-level. It consists of conglomerates, gravels, shaly limestones, and sands. The typical forms of fauna are: *Didacna crassa* Eichw., *D. praetrigonoides No. 1*, *D. surachanica* Andr., et cetera.

The Upper stage forms five terraces at the heights of 8, 5, 17, 26, and 35 meters above the level of the Caspian Sea, which is 26.5 meters below the ocean level. These terraces are composed of formations similar to strata of the Middle stage. Their fauna approaches the present Caspian fauna, and consists of: *Didacna trigonsides* Eichw., *D. pyramidata* Grimm., *Monodacna caspia* Eichw., et cetera. As exceptions, *D. crassa* and *D. bauer* are found.

The Recent deposits are represented by shore deposits of the present Caspian, rising 9.5 meters above sea-level at Bibi-Eibat and 40 meters at Artem Island. They contain fauna of the present Caspian, differing from the fauna of the Upper stage of the Ancient Caspian by the presence of *Cardium edule*, which is a form characteristic of seas of normal salinity, whence it migrated and adapted itself to the conditions of a semi-fresh-water basin. The period during which it penetrated into the Caspian Sea makes one of the most interesting pages in the geological history of the Black Sea-Caspian region.

Recent formations are represented also by different forms of continental deposits: (1) eolian and rainwash deposits: loess, loess-like clays, and dune ("barkhan") sands; (2) ejections of mud volcanoes: mud and fragments of various rocks; (3) lake deposits: silt, sand, and salt. Epeirogenic movements have involved not only the deposits of the ancient Caspian but have continued to the present. In the course of human history various sections of the region here described, especially on the shore of the Caspian Sea, have been subjected to uplift and subsidence. These slow oscillations from time to time have been superseded by paroxysms of the earth's crust—earthquakes and volcanic eruptions.

The writer found it necessary to dwell in more detail than the theme of this article requires on the stratigraphy of the southeastern Caucasus, especially the Apsheron Peninsula, as well as on the main points of its geological history, because the world literature on this subject has numerous references to the sources which at present are entirely out of date and have lost all practical significance. They do not conform to the data obtained by a close study of the actual geological features of this region, which for a geologist is one of the most interesting in the world.

Tectonics of Southeastern Caucasus

Tectonically the southeastern Caucasus is divided into two principal zones: (I) the folds of the Main Range—a zone of Jurassic and Cretaceous formations, and (II) the zone of submergence of the Main Range toward the southeast—a zone principally of Tertiary and partly of Cretaceous formations.

I. There are compact heavy masses close to the surface in the southeastern part of the first zone in the vicinity of Mount Dibrara and the village of Alty-Agach. This is the region of positive index of the acceleration of gravity. The highest reading near Alty-Agach is +81 units. On the southwest the zero isogamma passes somewhat northeast of the city of Shemakha, on the southeast, near the village of Dudar, and on the northeast at the base of the northern slope of Mount Dibrara. Above these heavy and compact masses is a series of Mesozoic formations of the Lower and Middle Cretaceous shales and arenaceous shales, and thick Upper Jurassic Titonian limestones. All these factors had their influence on the tectonics of the zone.

1. Here is a folded strip, approximately 12 kilometers wide, composed of Lower and Middle Jurassic series. This strip of the main Caucasian anticlinal range is characterized by: (1) the development of large folds complicated by smaller secondary folds, resulting from greater flexibility and plasticity of the shale formations; (2) a strong development of cleavage in the shales; and (3) the presence of large fractures along which the displacement of masses took place, in some places along steep fault planes with formation of overthrust faults of *Uebershiebung* type, and at fewer places, not yet definitely established along gently sloping fault planes with the formation of overlaps of *nappe de charriage* type.

The main direction of movement of the masses has not yet been definitely determined. Bogdanovich points to the overturning of folds both toward the south and north, and finds it possible that fan-shaped folding, and the displacement of the masses along the fault planes, took place in both directions. Later investigations indicate that mass displacement occurred almost exclusively southward. This contention, however, requires verification.

The southern limb of the main anticline, as distinguished from the northern limb formed by the Middle Jurassic strata, is composed of the Lower and Upper Cretaceous formations. A large fracture complicates the structure of this limb. The direction of this fracture coincides with the general direction of the Main Range. Along this line between the village of Vandan and Mount Niae-Dag, eruption of masses of diabasic type took place. Along the fracture, complicating

the northeastern limb of the main fold, are seepages of burning gases (in the Ninalug village district and at the base of the southern slope of Mount Shah-Dag) and hot springs are found (the Khaltan thermal line).

The folded Jurassic strip is submerged toward the southeast, and on its extension in the Mount Dibrara region folded structures are composed in part of the Lower, but principally of the Upper Cretaceous formations. This part is also characterized by the development of large anticlinal and synclinal folds, by fractures on the limbs, and by overthrust faults. It represents a natural extension of the folded strip of the Jurassic deposits.

East of the folded region begins the zone of the negative values of the index acceleration of gravity—the zone of a deep syncline.

2. North of the folded strip of Jurassic deposits, the folded strip of Shah-Dag extends a long distance. This strip is principally thick beds of Tithonian limestones. It is characterized by anticlinal folds and large gently sloping synclines between them. This strip extends southeast to Cape Killazin on the Caspian Sea. It begins with a complete fold, proceeds in the shape of only one of its limbs, and still farther in the form of separate huge cliffs, located between the Lower Cretaceous formations of Aptian-Barremian age.

The folded strip of Shah-Dag, like the previous one, is characterized by overthrust faults and large fractures on the limbs. Along some of the fractures are oil seepages and hot water. On Bogdanovich's map oil seepages are indicated near the village of Afurja on Velvelichay River and at the base of the northern slope of the Chirak-Kala Mountain. Signs of oil are found also on Cape Killazin, where at one time explorations for Mesozoic oil were carried on. The nature of folding of the Main Range zone is illustrated by a cross section through the Devichi-Shemakha line.

II. The second folded zone comprises the zone of submergence of the Main Caucasian Range at its southeastern end. From the standpoint of its geological structure, this zone can be divided into the following five parts.

1. Northern Kabristan, bordered on the south by the Sumgait River valley and by a strip of Pliocene deposits of the Shemakha region, and on the east by the Transcaucasian Railroad, is characterized by groups of branching folds, the central parts of which are formed by Mesozoic deposits. In the most northeastern group of folds and also in the fan-like folds developed in the northwestern part of the zone in the Astrakhanka district, central parts of the folds consist of Cretaceous formations, *Terebratulina* layers of the Aptian-Barremian

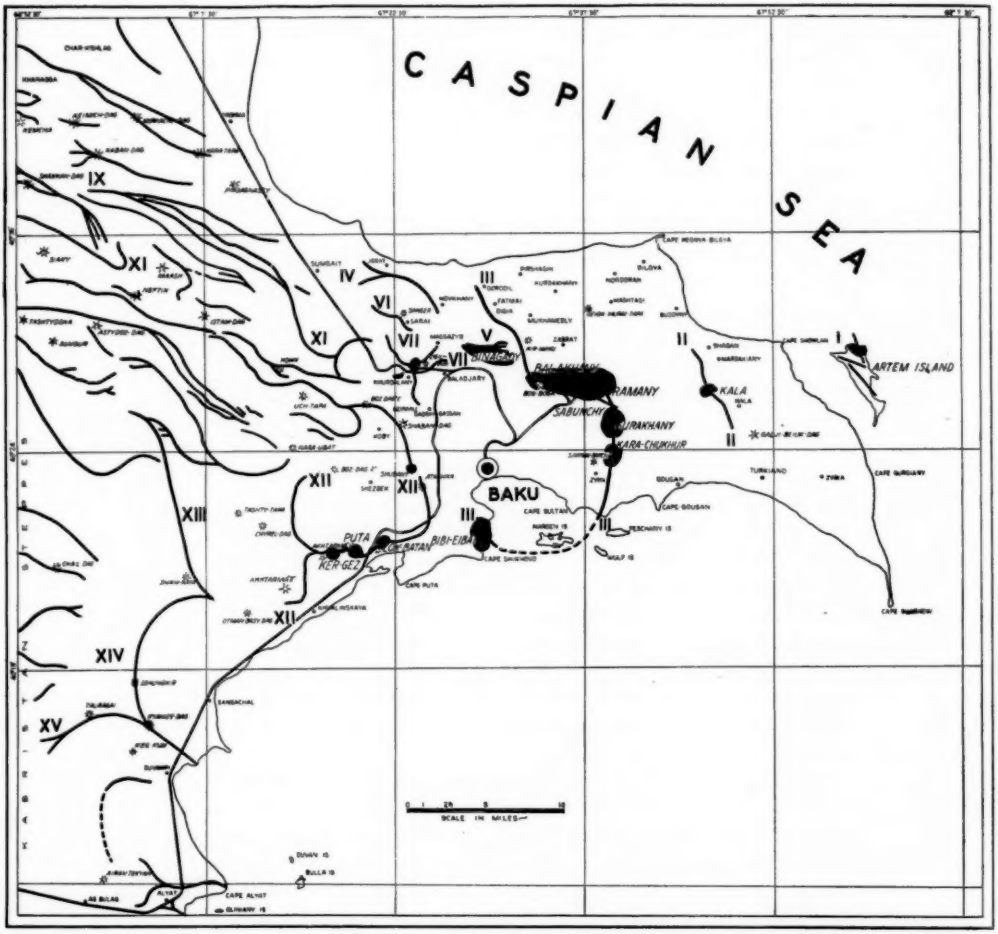

FIG. 7.—Map of Apsheron Peninsula, showing structural trends and location of oil fields. Trends indicated by Roman numerals are mentioned in text. Black areas: oil fields.

age, and the red Aptian series. In the branching folds farther southwest the corresponding parts are composed of the Upper Cretaceous formations.

The fold limbs and the broad and gently sloping synclinal folds which divide the anticlinal elevations consist of Oligocene and Miocene formations.

Of great importance here are the Maikop series, the *Spirialis* beds, and the Diatom shales. In only two places (in the region of the Mount Maash and in the region of Mount Siaky) the synclinal basins are of Pontian character, covered in the middle of the basin by layers analogous to the Productive series.

In the northwestern part of the region is a wide development of Pliocene formations lying unconformably on faulted Mesozoic series.

2. Along the Sumgait Valley and farther east to Mount Boz-Dag I (northern), a rather broad strip has been traced, consisting of the Kown series and forming several folds. Among them there is one especially prominent fold extending for dozens of kilometers. It emerges from the Sumgait River Valley, extends almost in the latitudinal directions, and passes through Kown Mountain and through the mud volcano Boz-Dag I. Here it changes its direction to that of the meridian, passes through the Chaban-Dag Range and Atashka Mountain to Lok-Batan. Here it again changes its direction, first to the latitudinal and then northwest.

This fold is here designated the Sumgait-Atashka-Puta fold. South of the Sumgait section of the anticlinal trend is a strip also extending practically in the latitudinal directions, composed principally of Miocene formations. At the central parts of the folds are outcropping Maikop strata and a few beds of the Kown series. On the south this strip is covered by faulted strata of the Productive series transgressively overlying the folds.

3. Central Kabristan is divided, almost through the middle, southeast and northwest, by Djeran-Hechmess River, which rises at the village of Marazy and flows into the Caspian Sea near the station of Sangachaly on the Transcaucasian Railway. Both banks of this river are formed mostly of beds of the Apsheron stage, in which in some places terraces of the Ancient Caspian have been preserved. Here extending in the same direction is an enormous synclinal fold, which opens widely in the direction of the Caspian Sea and, as its axis rises, gradually diminishes in the opposite northwest direction.

The greater part of this syncline is formed by beds of the Apsheron stage. It is bordered on all sides by beds of the Aktchagil stage through which rise outcropping strata of the Productive series. Along the upper

course of Djeran-Hechmess River this syncline is formed by beds of the Aktchagil stage and the Productive series. In the region of the Apsheron beds, the syncline is complicated by several dome-like elevations of diapiric nature, along which the biggest mud volcanoes of this region are located: Tauragai, Kianiz-Dag, and also Utalgi and Shikhi-Kaya. These dome-like elevations are located on three anticlinal trends: the first passes through Tauragai and Kianiz-Dag, and the second through the Utalgi Heights. In the Kianiz-Dag region these trends unite. The third trend comes up from the Shikhi-Kaya Mountain and slightly west of the mud volcano Otman-Bozy-Dag it unites with the Utalgy line. The first two trends display gently sloping arc-shaped bends. At the central parts of the domes outcrops of the Productive series strata are to be seen.

4. Southern and central Kabristan, situated southwest of the great Djeran-Hechmess syncline, is a region of Miocene and Pliocene deposits.

Of the Oligocene series, the Maikop series are found here forming the cores of the folds. In only a few places are Kown strata found in the core of the folds. Tectonically, along with the development here of secondary folding, there are large fractures, the most interesting of which are those along the Aliat Ridge and on the right shore of Pirsagat River, where, from a place called Akhtarma-Pashaly, they continue northwest to Shemakha Mountain. These fractures are in direct relation to the activity of mud volcanoes in this region. Large areas are covered here by extensions of mud volcanoes under which details of the tectonics of this area are hidden. The southwestern line of fractures coincides with the border between the submerged zone and the zone of rise of heavy masses in the Kura Valley.

5. The Apsheron Peninsula constitutes the extreme eastern part of the described tectonic zone. From the point of view of its geological structure it can be divided into three parts: (a) western, (b) northern, and (c) eastern.

a. The western part consists, geologically, at one of its ends, of the continuation of Mesozoic and Lower Tertiary folds, and is located in the zone of their submergence toward the southeast. At the other end of the region, folds of Miocene age are found. The Sumgait-Atashka-Puta fold, with its numerous branches, creates the impression of a closed anticlinal belt, embracing on all sides the synclinal basin of the Guizdek Hills, composed of Apsheron stage layers. This synclinal basin presents one of the peculiarities of the western part of the Apsheron Peninsula. South of it rise the Ker-Gez Heights (400 meters above sea-level), forming a part of a large syncline surrounded by a

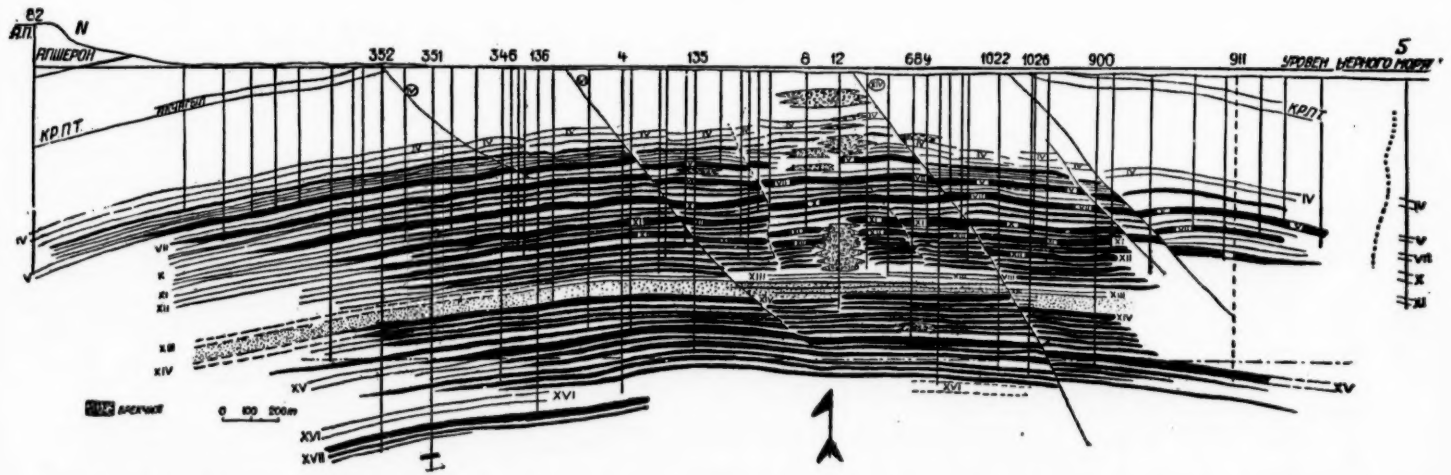

FIG. 8.—Cross section of Bibi-Eibat oil field. Black: oil sands. Arrow indicates positions of breccia of buried mud volcano. From V. A. Gorin, "The Bibi-Eibat Tectonics and the Prospect of Development of the Lower Division," *Azerbaijan Petroleum Industry* (Baku), No. 11–12 (November–December, 1933), p. 14, Fig. 3.

semi-circle of anticlinal trends of the Puta Valley and of the Kara-Dag area. The Guizdek Hills and the Heights of Ker-Gez are the highest positive points in the relief, but, technically, they are to be regarded as negative structural forms.

b. In the middle of the Apsheron Peninsula, a narrow strip of Aktchagil stage exposures—passing through the Jassamal Valley, the Baladjary Station of the Transcaucasian Railroad, Binagady-Shor, the northern shore of Beyuk-Shor River, and through the middle of the famous Balakhany-Sabunchy-Ramany oil field—divides the whole section into two parts: the southeastern and the northwestern. The southeastern, occupied by the Baku basin, which faces southward, slopes toward the Caspian Sea, and rises in several radial directions: west toward the Jassamal Valley, northwest toward Binagady-Shor; north toward Beyuk-Shor, and east toward the Zykh Heights. This is also a great synclinal basin, the closing slope of which on the southern side can not be seen, being hidden by the Caspian Sea. The Baku synclinal basin is built of Apsheron stage strata and by deposits of the Ancient Caspian terraces, among them the oldest beds of the Baku stage.

Northwest of the Aktchagil strip, up to the northern Apsheron Peninsula shore, extends the northwestern part, where the formations of the Productive series are mostly found. The Productive series strata form here broad and gently sloping synclines, as well as limbs of the fold, and, in some places, take part in the formation of the central sections of the Balakhany-Sabunchy-Ramany, Bibi-Eibat, and partly of the Binagady folds. But, in the main, the Productive series strata form synclines. In different places among these strata spots of the Ancient Caspian beds have been preserved from erosion in the form of terraces located at different heights.

The cores of folds are composed here of Miocene and Oligocene formations. Five folds pass through this section. 1. On the east, the peninsula is cut from northwest to southeast by the fold of the principal oil fields (trend III, Fig. 7) traced from the village of Gerodil on the north to the Zykh Salt Lands on the southern shore of the Apsheron Peninsula. 2. The Binagady fold extends almost in longitudinal directions. 3. The Kechal-Dag fold extends from the Kechal-Dag Mountain on the north to the Keiriki mud volcano at its southeastern end. In the composition of its central part the layers of the Kown series are the only ones of importance. These are surrounded by *Spirialis* strata and through them, in some places, outcrops of Maikop series emerge. This fold has two branches, one toward the northeast, in the direction of the village of Massazir, and the other southwest,

in the direction of the Zigil-Piri mud volcano. At the northwestern end of the Kechal-Dag formation is the Kechal-Dag mud volcano and on the southeast end the volcanoes Abich and Keiriki or Mud Hill. 4. The Sarai anticlinal fold is north of Kechal-Dag. Its core is composed of Maikop series surrounded by *Spirialis* strata. 5. The Novkhany-Djorat fold is located between the Sarai and Fatmai sections of the anticlinal line of the principal oil-bearing regions. Its cores are composed of beds of Maikop series.

c. The eastern part of the Apsheron Peninsula, separated from its middle part by a broad valley extending from the northern shore of the peninsula to the southern one, is formed at the surface by post-Tertiary deposits—terraces of the Ancient Caspian. Deposits of the Apsheron stage crop out: (1) in the district near the village of Kala, where they take part in forming the structure of the broad Kala anticlinal arch; (2) along the shore of the Caspian Sea, between Cape Kegnia-Bilgia and the village of Buzovna; (3) on the western shore of the Apsheron Strait, separating the peninsula from Artem Island.

Recent explorations have revealed in this region the presence of a few more anticlinal folds. The shore structure itself supports this contention. Artem Island consists of Productive series strata, showing complex anticlinal structure, complicated by factors of a disjunctive character. This is the region of negative values of the index of acceleration of gravity. Isogamma "100" limits, on the west, the whole Apsheron Peninsula, together with the adjoining parts of northern Kabristan, as well as a large area of southern Kabristan and the Saliani Steppes (Fig. 1). East of this line, toward the Apsheron Peninsula, negative values of the gravitational index equal −120 (in the oil-field areas) and even −130 units (on Artem Island).

The foregoing evidence shows that heavy masses lie here at a great depth.

On the basis of stratigraphic data the writer estimated that if the sequence of strata and the structure of the Mesozoic and Tertiary series remain unchanged throughout the whole Apsheron Peninsula, which can hardly be doubted, uppermost strata of the Lower Jurassic shale should be located here at a depth of not less than 10 kilometers. In the zone of the Main Range, at the summit of Mount Khinalug, they are raised to a height of 3,616.2 meters above sea-level, and on Tfan Mountain to a height of 4,352 meters, that is, the amplitude of the rise and subsidence is equal to almost 14.5 kilometers.

Pontian deposits in the area of Shah-Dag are raised to a height of 2,134.3 meters, and in the oil fields of the Apsheron Peninsula, for example in Surakhany, they are located at the depth of 2,000 meters;

therefore, the amplitude of the rise and subsidence equals 4,334.3 meters.

Therefore, both the geological structure data and the data of the pendulum survey indicate that, on the Apsheron Peninsula and in the region of the Kabristan Steppes, there is an area of great subsidence, which evidently began in the Mesozoic period, and with certain interruptions continued until the deposition of the Ancient Caspian terraces. Evidently after the folding, which took place during the Mesozoic age, and which lifted and turned into dry land the main Caucasian geosyncline, a part of the latter was left in the place of the region which we now call the region of subsidence. There the formation of sediments continued simultaneously with the gradual lowering of the base of the remaining geosyncline and with the active erosion of the uplifted mountain range. It is only by these facts that the enormous thickness of deposits on the Apsheron Peninsula can be explained. This statement is of special significance for the Productive series, the maximum thickness of which is 1,500 meters. Such a tremendous series could be deposited only with constant lowering of the bottom of the basin where this deposition took place.

The data collected in the study of geological structure of the southeastern Caucasus indicate that the process of submergence had been interrupted by temporarily quiet periods and by movements of a regressive nature. Of first importance among these stages is the eastern Caucasian orogenic phase which took place after the Pontian age before the Productive series was deposited.

The zone of submergence consists principally of Upper Cretaceous and Tertiary strata. The latter are mostly developed in facies of a clay character. In this complex, which is principally argillaceous, the following beds must be differentiated: (1) sandy clays of the Productive series, (2) limestones of the upper and middle division of the Apsheron stage, and (3) sandy marl complexes of Lower Tertiary formations, underlain by still more rigid strata of Mesozoic age. Such a lithologic structure, combined with other factors, has undoubtedly affected the tectonic character of the whole region and resulted in formation of peculiar tectonic structures.

Suess establishes the general condition that at the limbs of ranges and at their termini a special type of folding develops, in which an important part is played by branching folds and by groups of folds. This condition characterizes in the best possible way the zone of submergence here discussed.

Let us consider the principal features of a fold complex in the zone of submergence.

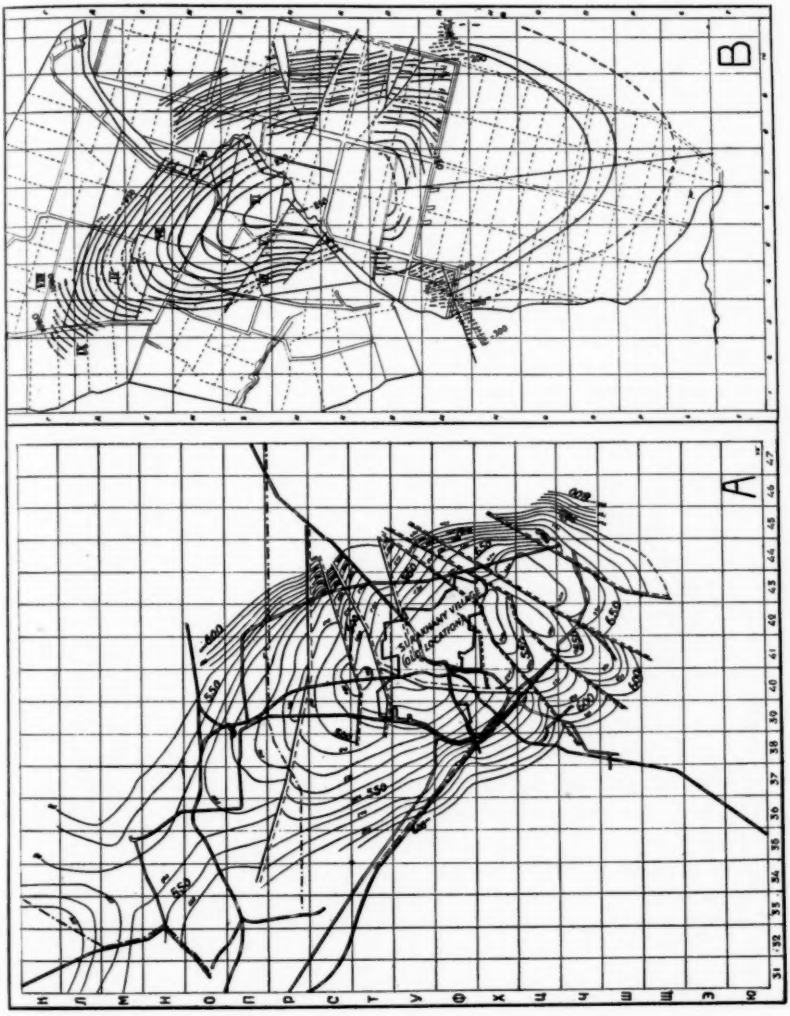

FIG. 9.—Subsurface structure maps.
A.—Surakhany field contoured on base of bed I of Surakhany formation. Contour interval: 10 sajens (70 feet).
B.—Bibi-Eibat oil field. Contoured on base of bed XIV, Balakhany formation. Contour interval in sajens (1 sajen = 7 feet). Scale: 1 inch = approx. 3,500 feet. By M. Nikitin.

1. The whole complex of folds of the zone of submergence consists of separate groups of folds and separate anticlinal trends traced for many miles. In general, groups of folds extend in the same direction with the main direction of folding in the Caucasus. This direction is most constant in the northwestern and western sections of the area. Separate anticlinal trends show great deviations from this main direction, which is especially characteristic of the Apsheron Peninsula and of the region of the Kabristan Steppes. Such deviations are especially noticeable in two particularly important trends of anticlinal folds, namely, the line III and the line XII (Fig. 7).

Through the middle of the Apsheron Peninsula extends a northwest-southeast anticlinal trend along which the famous Baku oil fields are situated: Balakhany-Sabunchy-Ramany, Surakhany, Kara-Chukhur. Wavy undulations of this trend can be traced from the northern shore of the Apsheron Peninsula to the southern. It is assumed that this trend continues along the bottom of Baku Bay, between the islands of Peschany, Wulf, and Nargen, the existence of which is evidently due to this extension.

The trend bends in arc-like manner toward the northwest and merges with the axis of the famous Bibi-Eibat tectonic structure. Thus the trend has the definitely expressed shape of a crane hook.

A similar hook-like shape is characteristic of the anticlinal trend XII, which passes through the mountains of Kown and Boz-Dag I (northern), the Shaban-Dag Range, Atashka (Eternal Fires) Lok-Batan, and the mud volcanoes of Puta Valley, whence, after branching, it extends toward the huge mud volcano Boz-Dag II (southern). The direction of the trend, as far as Boz-Dag I, coincides with the direction of the Main Caucasian Range, then follows the arc of the anticline encircling the synclinal basin of the Guizdek uplift composed of Apsheron strata.

2. Branching out is another characteristic feature of the complex of folds in the zone of submergence. This feature is typical of the folds on the Apsheron as well as in Kabristan. Especially characteristic in this respect is fold VII (Fig. 7), the so-called Kechal-Dag fold. It divides into two branches, one of which goes to the village of Massazir and the other to the village of Khurdalany.

The trend XII, of the Sumgait-Atashka-Puta fold, forms two folds near Boz-Dag I, and one near Ker-Gez which passes south into the Kara-Dag district. The points of greatest curvature and also the spots where the folds branch off are also the points where mud volcanoes are located.

In the Kabristan region, likewise, are many branching folds.

3. Another peculiarity of the group of folds in the zone of submergence is that each separate anticlinal trend consists of several dome-shaped structures which are located in chaplet-like manner along its axis and are separated from one another by saddles. It should be noted also that more of the old formations are found in the cores of the domes than in the arching parts of the saddles dividing them.

Such clear-cut, chaplet-like structure is particularly noticeable in the anticlinal trend passing through the oil fields of the Apsheron Peninsula. Eight domes are located on this trend in the following order, beginning at the northwest: (1) Fatmai, (2) Northern Kirmaku, (3) Southern Kirmaku, (4) Bog-Boga, connected with the famous oil field of Balakhany-Sabunchy-Ramany, (5) Surakhany, with the oil field of the same name, (6) Kara-Chukhur, with the oil field of the same name, (7) Zykh, and (8) Bibi-Eibat, with the oil field of the same name. Along this trend submergence still continues. Kown and Maikop strata were found in the core of the Fatmai dome. The core is enclosed by *Spirialis* strata. Only a small spot of Kown is found in the Kirmaku domes. They are formed principally of the Maikop series and *Spirialis* strata. In all the three domes the Productive series is displaced far to the limbs of the fold. In the Bog-Boga dome, in its very core, there is a small spot of Kown, surrounded by the Lower division of the Productive series. The Surakhany dome is formed by the lowest strata of the Middle Apsheron. Beds of the Productive series are found by drilling at a depth of 200 meters. The Kara-Chukhur dome consists of the upper strata of the Middle Apsheron, and the Zykh dome of still more recent deposits of the same Middle Apsheron stage. The Bibi-Eibat dome is composed of the uppermost layers of the Productive series. In the southeastern and southwestern directions it becomes submerged and covered by the Middle Apsheron strata.

The rise and fall of the axial line in the vertical plane, and the chaplet-like arrangement on it of separate dome-like structures, can be observed with the same distinctness also along the anticlinal trend XII, the Sumgait-Atashka-Puta line.

Also along this trend not less than 10 domes are located. Among them is the dome-shaped elevation of Mount Boz-Dag I (northern) in which the core consists of the Lower Kown strata (White Kown). This dome is remarkable because of the intense activity of the mud volcanoes on its summit.

The Mount Atashka dome, in the core of which strata of Maikop series are found, is famous because of its "Eternal Fires." It is connected with the Atashka oil field. Mount Lok-Batan is an active mud volcano, which every 3–5 years produces eruptions of mud accom-

panied by ignition of gases. On its north flank is the famous Lok-Batan oil field, discovered in 1932. West of Lok-Batan are several domes of the Puta Valley. Each is connected with newly discovered oil fields, the richest being the Ker-Gez field.

The structure of the Mesozoic anticlinal trends in the northwestern part of the region does not present such a regular chaplet-like arrangement of dome-shaped elevations. Mesozoic structures represent brachi-anticlinal folds, ordinarily having a complex structure of the core in the form of a complicated anticlinal fold with a steep and, in places, overturned position of its strata. These folds display the same phenomena of submergence toward the southeast, and the undulation (rise and fall) of their axis in the vertical plane. Especially interesting in this respect is the XI Yunus-Dag anticlinal trend which the writer explored in 1914. It represents a group of folds following three anticlinal trends. In the northwestern part of the Perekishkul Plateau it shows the undulation of its axis in the vertical plane. Toward the northwest and east the fold becomes simple. Toward the southeast it breaks into several domes, on which, as its axis plunges, more and more recent deposits of the Lower Tertiary crop out. After crossing the railroad near the Guizdek Station the fold spreads and is covered by Miocene Diatom strata.

The regular chaplet-like arrangement of domes and the submergence of axial trends toward the south may be observed also in several separate anticlinal trends in the area of the Kabristan Steppes. These typical features, therefore, are characteristic of the whole zone of submergence.

4. Let us turn now to the fundamental question of the structure of the domes proper. Here we can distinguish, by their exterior form, two types of domes: domes of normal anticlinal structure, and domes of diapiric structure, or folds with a piercing core (*plis diapir a noyaux de percement*). Surakhany, Bibi-Eibat, Kara-Chukhur, Kala, et cetera, are examples of domes of normal anticlinal structure.

The Surakhany dome is formed by strata of the Middle division of the Apsheron stage. The long axis of the dome extending northwest and southeast is somewhat curved with the convex side toward the east. The Middle Apsheron strata of the central part of the dome lie within the limits of the Surakhany Lake, whence they dip northwest and south. In the deeper strata of the Productive series the axial trend is found to be considerably displaced toward the east. The central part of the dome is located at the site of the old village of Surakhany. The present village is outside the oil-field area. The dome is separated from the east end of the Balakhany-Sabunchy-Ramany fold by a dis-

tinct saddle. Another saddle separates it from the more southern, recently discovered Kara-Chukhur dome.

The southeastern and eastern part of the oil field is broken by a system of faults the direction of which is shown on the map (Fig. 9A).

On the Surakhany dome, oil is found in the sands of the Productive series, filling its arching strata. The contours of the oil reservoir have an elliptical form. Down the dip the oil-bearing horizons contain water. The magnitude of the closures is different for each bed. At Surakhany the upper division of the Productive series is being exploited, that is, the oil-bearing beds of the Surakhany, Sabunchy, and Balakhany series. Test drilling of the Lower division of the Productive series is also carried on. Several wells in these horizons have already produced oil (see the section and the structural map of the Surakhany oil field, Figs. 4 and 9A).

South of the Surakhany dome is the recently discovered Kara-Chukhur dome (Fig. 6A). The dome is broken by two branching longitudinal faults.

The Bibi-Eibat dome has an oblong shape with the longest axis extending northwest and southeast. The top of the dome is formed by Aktchagil strata and by the upper beds of the Productive series, and its limbs by the Upper and Lower divisions of the Apsheron stage. Bibi-Eibat consists of two parts: the old and the new or the "Bay." The old part is situated on the mainland, and the new on the filled-in portion of Baku Bay. The filling in of the bay was undertaken when geological research showed that only a part of the oil-bearing district is situated on the mainland, and that the other part continues under the sea. The structural maps show the structure of Bibi-Eibat dome at the depth of the Productive series. It is seen from the map that the dome is of a double nature. Drilling disclosed the presence on the secondary southern dome of a mud volcano, which contaminated a certain small portion of the oil field. The limbs of the dome, especially the eastern, are complicated by a series of transverse faults. Oil lies in the arching parts of the strata. At present sixteen oil-bearing horizons are being exploited in the old area and the Upper division of the Productive series in the "Bay." (Figs. 5, 8, and 9B.)

The Kala dome is 12 kilometers east of Surakhany. It is a very gently sloping structure covering a large area and formed on the surface by the Middle division of the Apsheron stage. The limestones of this division outline very distinctly the structure of the oil-bearing formation. The cover of the Productive series lies here at the depth of more than 400 meters. Particularly interesting on the structural map is the transverse fault dividing the whole structure into two parts:

the northern and the southern. The northern part is an extremely rich oil- and gas-bearing area, but the southern is barren in the Upper division of the Productive series, at any rate. For several years the exploration of this part of the Kala dome proved to be futile. It was

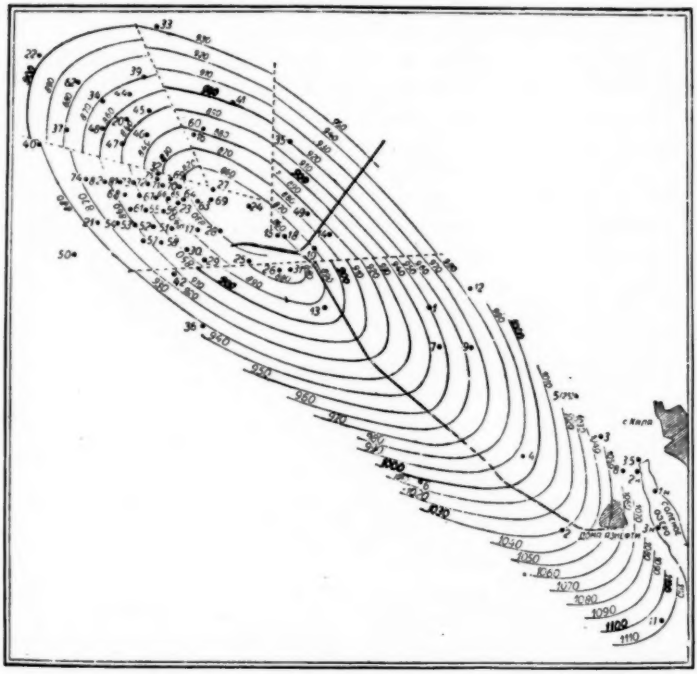

FIG. 10.—Structural map of Kala oil field contoured on base of horizon I, Sabunchi formation. Contour interval 10 sajens (70 feet). From I. Tolbin and K. Mashkovitch, "The Results of the Prospecting Drilling in the District of Kala During the First Half of the Year 1933," *Azerbaijan Petrol. Indus.* (Baku), No. 10 (October, 1933), p. 10.

found that above, in the Apsheron strata, the apex of the dome was situated not over the arching parts of the oil-bearing beds, but over their southeast flank.

Other domes, similar in type, are not yet of industrial importance.

Let us now proceed to domes of diapiric type.

The conception of diapiric structures was first introduced into geology by L. Mrazec. He established this type of folds in studying first the saline and then the oil-bearing districts of Roumania. According to his definition a diapiric fold, or a fold with a piercing core (*plis diapir*

a noyan de percement), is a structure in which the core, consisting of salt or of some other plastic substances, has pierced the more recent strata situated above it. He regards such folds as "the result of unequal action of tangential forces on a complex of strata" in the course of a folding process that had been continuing throughout the whole deposition period. Accordingly

> the lower strata of the complex were subjected to more active folding than the overlying, more recent strata, which had been only slightly affected by tectonic processes or totally free from their action. For this reason the arch of the upper strata had been pierced by the steep fold of the lower strata.

Mrazec regarded saline domes as one of the extreme forms of diapiric structures, that have all originated in one common cause.

Karl Krejci, in determining the nature of diapiric folds, considers the duration of the fold-forming process a secondary factor and makes a distinction between the phenomena of diapirism proper and saline intrusions. He holds that side pressure alone does not suffice to account for uplifting the saline core to the height of more than 1,000 meters.

Ernst Blumer in general recommends care in the use of the term "piercing folds" (Durchspiessungsfalten) which he considers inappropriate. He holds that "piercing folds" are simply folds compressed so strongly that the core has already lost the characteristic arching structure. This phenomenon can be observed in any fold, provided the horizontal pressure has reached sufficient intensity. These sharply compressed folds of strongly faulted formations are the reverse of the broad arching structures of the regions of moderate folding. This explanation can not be regarded as satisfactory for the reason that the diapiric folds are especially numerous at the peripheries and ends of mountain ranges that are characterized by phenomena of weakened or fading folding, and also for the reason that this explanation effaces the contrast between the real diapirism and the fold-forming process.

M. Kraus has particularly interesting views on the nature and the causes of formation of the diapiric folds and the part played by them in formation of the oil fields. He holds that the structural forms of diapiric type are generated by vertical pressure, and that the form and the manner of formation of these structures can not be explained by tangential pressure. On the basis of technical experience and the phenomena of nature, he maintains that only those rock formations are subject to such peculiar tectonic processes in which the internal and the external friction under the given mechanical tectonic and physical conditions is not above a certain value. In this category must be placed first of all such formations as rock salt and the so-called "in-

competent" (according to terminology of some American geologists) formations capable under certain conditions of becoming plastic under pressure. The structural form created by vertical pressure represents a fault surface, having curvature of a logarithmic spiral and turned by its concave side in the direction of maximum pressure.

Depending on distribution and on the arrangement with respect to one another of the zones of high and low pressure, the forms of the final phase represent something like an overthrust with one-sided limitation by a logarithmic spiral surface or a fan-like fold (in case of a two-sided limitation) or a dome, limited by a spiral surface on all sides. Such are the morphologic and the genetic features of the diapiric structures according to Kraus.

It is interesting to note also the views of Bogdanovich on this subject, because they belong to the most recent time. He writes:

> In order to avoid misunderstandings it is necessary to define accurately what is understood under the term diapirism, and, to conform to the intention of the author of this term, the definition should be limited to folds in which a core of older formations pierced through a mantle of younger beds (piercement folds).

Furthermore, he notes that wherever the pressure was not sufficiently strong, forms may have been originated showing only the difference in dip of the upper and the lower strata within the limits of the same diapiric structure. As the principal external features of diapirism he considers (1) a very steep dip of the strata in the central part of the fold, (2) a weakly manifested asymmetric nature of the fold, and (3) the absence in many cases of a governing direction of overturning.

By these distinguishing characteristics a diapiric structure differs from an ordinary asymmetric fold. His conclusion is as follows:

> The diapiric structure is therefore an individual form of structure, independent of the dip of formations, but dependent on movements, principally in the upward direction.

In recent time there were, among geologists working in the Baku region, some daring attempts to generalize the phenomena of diapirism and to extend them to a series of tectonic structures, which do not fall under the conception of diapirism either from the morphologic or from the genetic standpoint. Thus, for example, an opinion is voiced whereby the structures connected with the buried forms of relief are to be regarded as diapiric. As an example of such a form is cited the Chusov Gorodki formation of the western Ural, which to this day gives no evidence whatsoever of any faulting. Or, to cite an-

other example, all the saline domes of the Ural-Emba district have been included wholesale in the group of diapiric structures, whereas we still have no accurate knowledge of the relationship of saline cores to the strata enclosing them, owing to the absence of strictly verified data.

The foregoing discussion shows that in defining a diapiric structure there are two aspects to be considered: the morphologic, and the genetic.

The basic morphologic feature is seen in the presence of a considerably faulted core of the fold, composed of older formations than the enveloping series forming the limbs of the structure. By their internal structure such folds fundamentally differ from the ordinary folds generated by tangential forces. They lack the usual arching bend of strata as well as its further modifications arising in the course of folding. Instead of that, there is here a considerably deformed kernel in which the strata are either pitched up vertically or overturned or crushed to such an extent as to make it difficult to determine the elements of their position. The younger strata enveloping the core also have been affected by the action of this "piercing," and the force of this interaction is inversely proportional to the distance of various strata forming the limbs from the center of piercing. In connection with this, the dip of the strata also changes from a very steep dip at the center to a very gentle dip at the periphery. This change of dip takes place at right angles as well as in the direction of the axis of the folds, which ordinarily plunge rapidly in the opposite direction.

The peculiarity is noticeable not only with respect to the dip but also in the structure of the limbs of the fold. One limb does not resemble the other, either in composition of the series forming it, or by the extent of their dislocation, or in thickness of separate strata, as can be clearly seen on a section of a typical diapiric structure through the axis of the fold.

Periclinal termini of diapiric structures are characterized by fan-shaped arrangement of dip lines and by gradual diminishing of dip in the direction of plunge of the fold's axes. On a periclinal terminus a section through the fold at right angles to its axial line will not differ in outward appearance from the section through a normal dome-shaped fold.

At times the piercing force is so great that it not only affects the dip of the limbs but also causes faults in the peripheral portions of the structure, situated at a considerable distance from the core. Thus, for example, in the Baku region, where the Lower Apsheron and the Aktchagil strata lie conformably, in some diapiric structures with the

piercing core of Maikop strata, the Lower Apsheron has been found directly to overlie the Productive series, that is, the omission of the Aktchagil strata of about 50 meters in the thickness has taken place.

To judge by the data collected on the Apsheron Peninsula, faults frequently occur as secondary phenomena in the formation of diapiric folds, and can be regarded as an accompanying feature of diapirism.

Intensification of phenomena of disjunctive dislocation in the course of an ordinary (tangential) folding may lead to development of overthrust faults and of small overlaps. With the exception of new data obtained by deep drilling on Artem Island, giving evidence of a fracture in the fold and of a movement along the fracture plane (a very steep one) of one of the limbs (a fault of *Ueberschiebung* type, or overthrust fault), no such phenomena have been noted so far within the limits of the Apsheron Peninsula.

Such is the morphologic character of diapiric folds. Their character, however, is closely connected with their genetic features. A tectonic structure with the previously enumerated morphologic features could be originated only by masses possessing upward movement—this is the basic feature of diapiric structures closely connected with their morphologic nature.

Tangential forces, caused by contraction of the earth's crust and acting on a regional scale, could not be the sole cause of tectonics of such comparatively small, but extremely complicated structural units. Their structure points to some concentrated force acting upon a comparatively small area.

In the process of folding, at the time when deposits had been forming, tangential forces had, apparently, already predetermined the lines along which anticlinal folds are situated. On the one hand, they created weakened points at the arching portions of anticlines and, on the other hand, they caused unevenness of the underlying strata which resulted, in turn, in the uneven accumulation of deposits. This uneven accumulation of deposits originated zones of high and low pressure which, in turn, led to the further differentiation of the process where the predominating importance was assumed by the force of gravity, the force of vertical pressure acting upon plastic masses and impelling them to move along the lines of least resistance into the zones of low pressure.

The writer does not understand why some authors regard diapiric structures as the result of a fold-forming process, and the extrusions of salt in piercing cores as mostly the result of gravitational pressure on areas of more gentle folding.

Diapiric structures, which in Roumania and in other localities are

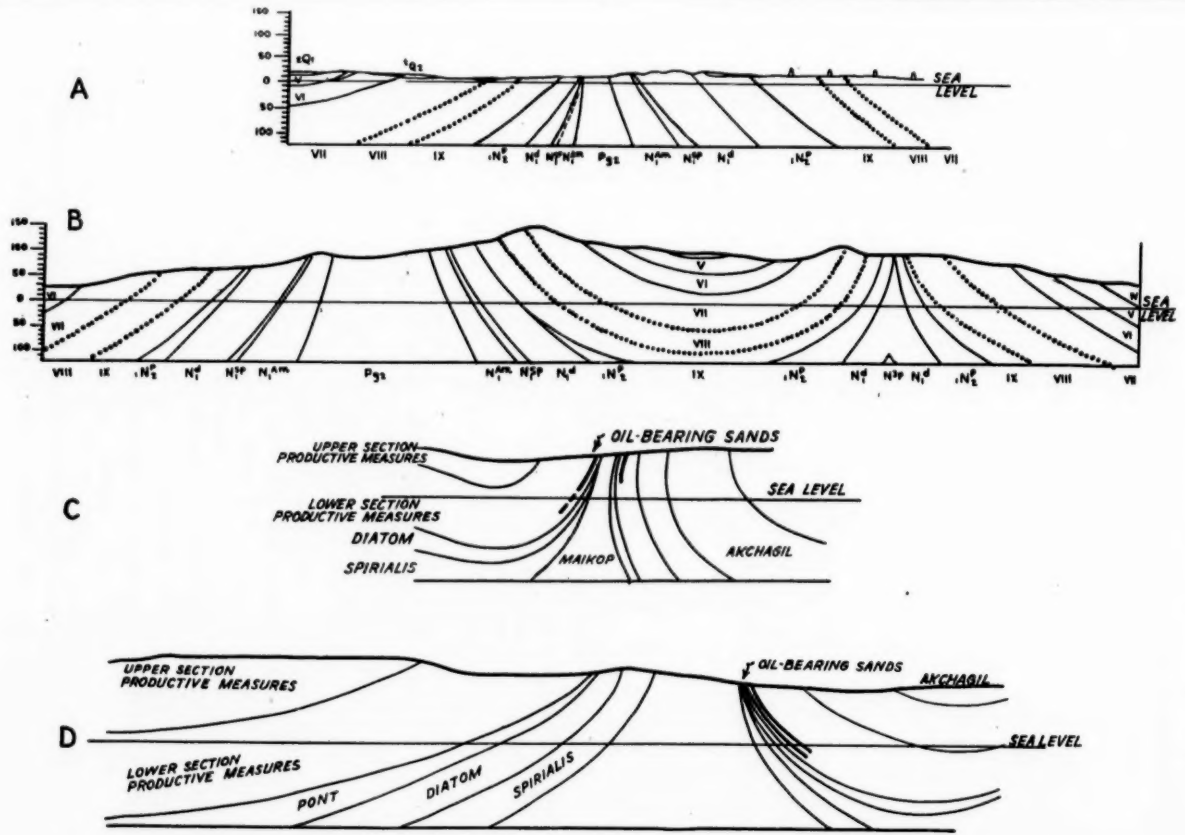

FIG. 11.—Typical examples of diapiric structure in cross section. A. Binagady fold, according to Golubiatnikoff. Oil wells at right. Scale in sajens (1 sajen = 7 feet). B. Shaban-Dag. Hurdalany oil wells at right. Scale in sajens (1 sajen = 7 feet). C. Kaphtaran-Agzy-Kiry. D. Kir-Kishloe.

the sites of the richest oil fields, naturally attract the attention of geologists, especially of those exploring oil-bearing regions.

The writer came across structures of this type in the course of geological work in the northwestern part of the Caucasus (between Anapa and Temriuk) and especially on the Taman Peninsula in 1911–1912. In the succeeding years, 1913–1916, similar structural forms were found on the Apsheron Peninsula. Their description is contained in the writer's works published at that time by the Geological Committee.

In these districts, situated on two opposite ends of the Caucasus, the fold-piercing core consists of massive argillaceous beds of Lower Tertiary age: the clays of the Maikop series and the marly clay beds of Lower Tertiary horizons (Kown, Ilkhi-Dag, Sumgait series, et cetera).

At present this tectonic structure receives, in the Soviet geological literature, general recognition denied it heretofore. As previously shown, there is now an opposite tendency to broaden the meaning of this conception.

The following are examples of diapiric domes on the Apsheron Peninsula.

1. On the anticlinal trend III (Fig. 7), passing through the principal oil-bearing districts, are: (a) the Fatmai dome, (b) two Kirmaku domes, (c) the Bog-Boga, or the Balakhany-Sabunchy-Ramany dome.

2. On the anticlinal trend V is the Binagady dome.

3. On the Kechal-Dag anticlinal trend VII are: (a) the Keiriki dome, (b) two domes of the Zigil-Piri branch, namely, Zigil-Piri and Sula Tepe.

4. On the anticlinal trend XII, passing through the Kown, Boz-Dag, Shoban-Dag, Atashka, Lok-Batan and Puta, nearly all domes are of diapiric structure. Among them the domes of the Puta Valley and Lok-Batan are of the greatest industrial importance.

On the Kabristan Steppes most domes situated on the anticlinal trends have diapiric structure.

In order to establish the importance of these structures with respect to their relation to oil-bearing properties of a region, we shall now describe some of the more important.

The Bog-Boga or Balakhany-Sabunchy-Ramany dome is the most remarkable in this respect. It represents a structure of an incompletely developed but a clearly expressed diapiric type. The piercing core is exposed at Mount Bog-Boga, which is also an extinct mud volcano, whose slopes are covered by former mud extrusions and display abundant oil seepages. The piercing core is composed of crushed clays of

the Kown series. In its upward movement it left unexposed the strata of the Maikop, *Spirialis* and Diatom series, the Pontian stage, and some of the horizons of the Lower division of the Productive series, and came into direct contact with the higher horizons of the same Lower division, which envelop the core on all sides. The fold becomes submerged east and west of Mount Bog-Boga. At the western submergence it is composed of strata of the Lower division of the Productive series; its submergence changes into a rise in the direction of the South Kirmaku dome. At the eastern submergence, all the series

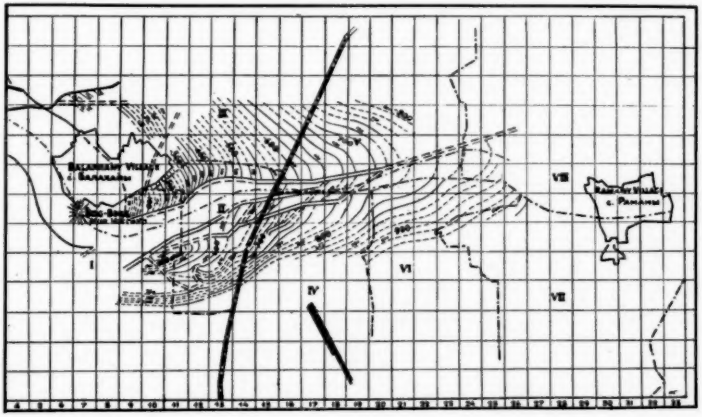

FIG. 12.—Structural map of Lenin district (Balakhany-Surakhany-Ramany oil fields). Contoured on top of bed C of post-Kirmaku shales (N.K.G.). By A. I. Krems. Contour interval: 20 sajens (140 feet). Scale, 1:67,200.

of the Lower and Upper divisions of the Productive series are developed, followed by the Aktchagil, Lower Apsheron, and near the village of Ramany the fold is covered by the Middle Apsheron limestones. Farther east the fold gives place to the saddle separating it from the Surakhany dome. All this region is characterized by fan-shaped arrangement of all the series in curving directions.

A structural map compiled by A. I. Krems (Fig. 12) gives an idea of the tectonics of the Lower division of the Productive series. The map shows that the whole arching portion of the structure is broken by a series of faults. Krem's map pictures also a great branching fault, whose direction closely approaches the direction of the axial line of the fold.

In this part of the field oil has filled all the sandy strata along the arching part of the dome from Mount Bog-Boga to the village of Ramany, an area about 6.5 kilometers long and about 3 kilometers wide. Farther east oil fills the strata composing the saddle between the Surakhany and the Bog-Boga domes. As a rule, accumulations of petroleum in the beds are supported by water on the limbs of the fold.

The western part of the fold, situated on the northwest slope of Mount Bog-Boga and known as the Khorassany sector, also contains oil, but in smaller quantities than the east part. The core of the fold, in spite of the numerous seepages of oil around it, is of no industrial importance. In general, it must be strongly emphasized that oil has accumulated on the east part, in the zone of its submergence. In pre-Soviet time this field was exploited only in the oil-bearing horizons of the Upper division, but under the Soviet Government the exploitation was extended to the Lower division, causing a notable revival of activity in the Balakhany district, which before the Revolution had completely ceased. At present, however, the Lenin district, which includes the Balakhany, Sabunchy, and Ramany oil fields, occupies in production of oil one of the first places in the Soviet Union (Fig. 12).

The Kirmaku dome has a piercing core composed of crushed clays of the Maikop and Kown series and is enclosed by *Spirialis* beds. On the limbs there are thinned outcroppings of Diatom strata and of the Pontian stage. The Productive series is shifted to the limbs of the fold and forms by its lower horizon the saddle between Mount Bog-Boga and Mount Kirmaku. Consequently, it is a more open fold than that of Balakhany-Sabunchi-Ramany. Oil has accumulated here at the submergence of the fold toward the southeast in the lower horizons of the Productive series and partly in the west limb. So far the industrial exploitation of this field has not begun. Before the Revolution oil was obtained in a primitive manner by means of shallow wells.

The Fatmai dome has a core composed of green clays of the Kown and clays of the Maikop series. It is enclosed by *Spirialis* beds. The strata of the Diatom series of Pontian stage and especially of the Productive series are displaced far to the limbs of the fold. The whole central part of the fold is barren of oil. Oil is found in comparatively small quantities in the lower strata of the Productive series, in the zone of submergence of the fold toward the southeast. It is also found on the southwest and southeast limbs of the fold, in the sands of the same Lower division of the Productive series, in the portions of the limbs which are nearest the submerged part of the structure.

It can be seen that the Fatmai dome represents a most open diapiric structure and also one of the poorest in oil.

The Binagady fold presents a typical example of diapiric structure (Fig. 11A and Fig. 13). Along the axis of the fold, which almost coincides with the direction of the latitudinal line, emerges a narrow strip of light gray marls and clays of the White Kown, constituting the piercing core of the fold. From the north and south this core is enclosed by Diatom beds. On the north limb they crop out in the form

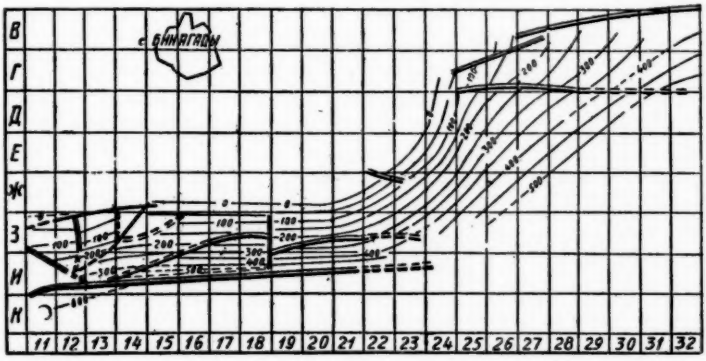

FIG. 13.—Structural map of Binagady (Kirov) oil field. Contoured on top of post-Kirmaku shales (N.K.G.). From I. Furman, "Kirmaku Series Sections, East Part Baku Semi-Circle Oil Fields, from Electrical Coring Data," *Azerbaijan Petrol. Indus.* (Baku), No. 8 (August, 1933), p. 75, Fig. 5.

of a narrow, interrupted strip; on the south limb, on its western part, the strip is fairly broad, and on the east it gradually narrows and finally disappears in the zone of the eastern submergence of the fold. The presence of Pontian formations on the north limb is not fully established, but it is most developed on the south limb, on its west part. Toward the east its outcrop gradually narrows and, like the Diatom series, finally disappears under the Productive series at the east submergence of the fold. On the north limb the Lower division of the Productive series approaches close to the core of the fold. Here it is divided from the core by a large fault which complicates the Binagady structure. The whole north limb of the fold is faulted. That is why the lower division of the Productive series is almost entirely out of sight. On the south limb the Lower division is almost fully developed. Though on the north limb beds of the Productive series approach almost to the very core of the fold, on the south limb they are almost a kilometer removed.

The eastern submergence of the fold is complicated by several lon-

gitudinal faults. The richest accumulations of oil are found principally in the Lower division of the Productive series, on the south limb of the fold. Especially rich in oil are the strata not emerging to the open surface which became sealed as a result of the diapiric structure of the fold.

Recently oil has been found at the eastern submergence of the fold and in the faulted north limb, as well as in the lower beds of the Productive series. The central part of the fold, and especially its core, have been proved quite barren. Two extinct mud volcanoes are situated in the central part of Binagady structure.

The Chatal-Dag anticlinal trend VII represents really a branching brachi-anticlinal fold with the axis undulating in the vertical plane, generating thereby several dome-shaped uplifts. Both these domes and the saddles between them are composed of White Kown strata. The structure of the central part of the fold and of its limbs is distinctly diapiric, so that from the morphologic and the genetic point of view we may call this structure a brachi-anticline of diapiric type. On its dome-shaped elevations several mud volcanoes are situated: Keiriki (the Mud Mountain), Abich Volcano, and Kechal-Dag (northwestern end).

At the base of the south slope of Mount Keiriki is the Mud Mountain oil field which has oil in the Lower division of the Productive series. Here the formation of oil reservoirs and their preservation was unquestionably affected by the diapiric nature of the whole structure.

The lowest horizons of the Lower division of the Productive series remained here unexposed to the open surface and became sealed in the upward movement of the core of the fold.

The Sulu-Tepe dome, or Sulu-Tepian meridional brachi-anticline, as D. V. Golubiatnikov called it, has a core composed of Diatom series and Pontian strata, and limbs composed of various horizons of the Productive series. The Lower division is thin, for most of it has been squeezed out by the piercing core. This condition affected the oil-bearing properties of the strata. Oil wells on the east limb of the fold, near the contact with the core, gave a small output of 5–10 tons per day. The oil well No. 101, on the same limb, but considerably farther down the dip, produced a tremendous gusher which gave about 15,000 tons of oil in 2 days. (Fig. 14A.)

The southern submergence of this structure is unexplored, but great hopes are attached to it. The core of the fold proved to be barren of oil in commercial quantity.

Between Sulu-Tepe and the Keiriki mud volcano the entire outcrop of the Productive series for several kilometers is particularly in-

teresting for oil exploration, because the tectonics of this region has all the distinguishing features of diapirism.

The Atashka dome situated on the anticlinal trend XII (Fig. 7) is also a typical diapiric dome. Its core is formed by beds of the *Spirialis* and the Maikop series. The southeast limb is tilted vertically upward and in places is overturned. It presents a case of omission of some series due to the squeezing out of several beds. The west limb slopes somewhat more gently, but still has a fairly pronounced dip near the center. Both limbs are composed of Productive series beds. In the

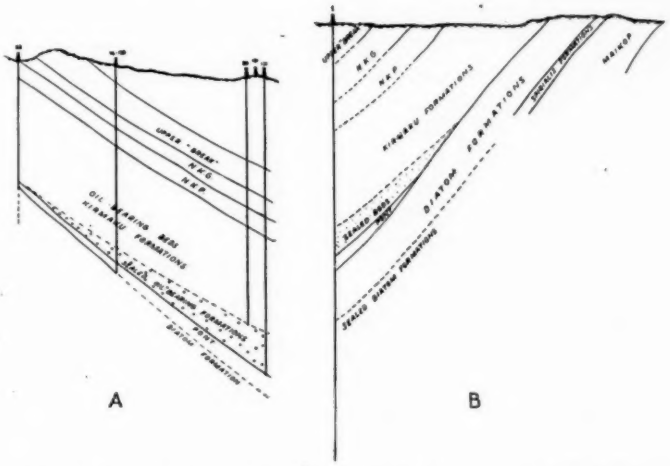

FIG. 14.—Sealed oil-bearing formations. By A. I. Mesropian. A. Sulu-Tepe Scale, 1:10,000. B. Zigil-Piri district. Scale, 1:7,500.

center of the core there are seepages of natural gas which had been burning up to very recent time (Atashka—"Eternal Fires"). Oil is found at the base of the Productive series, at the southern submergence of the fold. On the northern submergence of the fold, oil is found in the strata of the Diatom series.

Lok-Batan is situated on the same anticlinal trend, at the point where it abruptly changes its direction from the meridional to the latitudinal. A mud volcano is situated exactly at the bend, on its outer side. It is difficult to say what strata were uplifted in the core of the dome because the slopes of the volcano are covered by a layer of volcanic breccia about 30–40 meters in thickness.

As whole blocks of Maikop clays have been found among the vol-

canic breccia, it may be inferred that the core is composed of these clays, which apparently pierced the lower horizons of the Productive series.

Similar to Bog-Boga, Lok-Batan is also a dome of semi-open type. This, apparently, accounts for its great wealth of oil proved by recent wells and especially by well No. 45, a gusher which for 15 days flowed daily 15,000–20,000 tons.

The geological structure of the Puta Valley acquires every year greater and greater importance as a new oil-producing region.

It is not necessary to repeat the description of other oil-bearing diapiric structures. All show the same regularity: the open diapiric folds, the piercing core, and, in general, the central parts of the fold are barren of oil. At times mud volcanoes are situated on this part of the structure. Oil has accumulated in the submerged zones of the structure and on the limbs of the fold in beds of the Productive series sealed by the piercing core. In semi-open structures, oil is found practically in all parts with only the exception of a small area occupied by the core itself. The richest oil-bearing horizons are in the arching part of the fold.

The Kabristan diapiric domes are formed in accordance with the same law, and their oil-bearing properties are governed by the same principles as on the Apsheron Peninsula. The industrial importance of these structures, with a few exceptions, is undetermined because the greater part of them is unexplored.

The northwest part of the Apsheron Peninsula, as was already mentioned, is characterized by the development of brachi-anticlinal folds, the central parts of which are composed of Upper Cretaceous strata or of Flysch formations of the Eocene. These structures involve all the features of diapirism and, like the Kechal-Dag fold, should be classified as diapiric brachi-anticlines. In short, diapirism is the general law in the tectonics of the whole region of the submergence of the southeastern Caucasus. The writer may be accused here of contradiction, because in describing dome-shaped structures he has differentiated between the domes of normal and of diapiric structure. According to their shape, from a geomorphologic point of view, they are normal domes, but genetically they are simply undeveloped diapiric structures, arrested in certain primary phases of their development. Similar to the typical diapiric structures situated with them on the same tectonic trend, they have the same causal origin. No one could reasonably hold that the Bog-Boga district was subject to one set of tectonic factors and the Surakhany district, 10 kilometers away, to others.

The originating cause is the same, but the phase of development of

diapirism is a different one. Oil accumulation and the formation of oil-bearing beds of the southeastern Caucasus are closely connected with diapirism and are determined by it. This is the reason for attaching so much importance to the investigation of this phenomenon. The writer can not, therefore, agree with his highly respected teacher, Professor Bogdanovich, that the importance of diapiric structures is overrated. Their rich or poor content of oil must be judged, not by the Taman Peninsula, where there has been no serious prospecting; not by the Atashka, which is not yet exhausted; and not even by Binagady, which in 1932 yielded 418,000 tons of oil;[4] but rather by the production of Lok-Batan, which is an example of diapiric structure. In the beginning of this article and elsewhere the writer has frequently referred to the fact that the zones of submergence in the southeastern Caucasus are classic regions of the development of mud volcanism. Here Professor Koralevski has recorded and described about 160 major and minor mud volcanoes. The majority of these are closely connected with the diapiric structures situated either in the piercing cores themselves or in their proximity. There are only isolated examples of large mud volcanoes located in the synclinal folds of the strata: Davali-Dag, in the Kabristan Steppes, and Otman-Bozy-Dag, on the shores of the Caspian Sea. The real tectonic character of these localities is not known, as everything is covered by a thick mantle of mud ejections. From the geological data of some anticlinal structures of the Kerch Peninsula, deeply bent anticlinal arches are known to be filled with deposits of more recent origin than those forming the arch itself. In the Djerjav anticlinal arch, which is formed by beds of the second Mediterranean stage, Sarmatian limestones have been pressed into the arch of the fold. It is possible that this is a similar situation, especially since the Otman-Bozy-Dag volcano is located along the continuation of two anticlinal trends (XIV and XII), which meet somewhat west of the volcano.

The foregoing review of the geologic formations of the whole zone of submergence leads to the conclusion that all these phenomena—geologic structure, oil-bearing, and mud volcanism—comprise a complete genetic whole. It shows that gas and oil formation, and mud volcanism, are functions of the same common cause, namely, the effects of geologic structure and in particular the effects of a special form of tectonics—the diapiric structures. Diapiric structures, oil fields, and mud volcanoes form a whole unified system in the process of the geological development of the region of submergence and of

[4] The Binagady district in 1932 yielded about 80 per cent of the production of the Drogobysk district in Galicia and about 65 per cent of the whole production of Poland.

subsidence of the Caucasian Range. This process commenced very far back, when only a section of the geosyncline remained from the main geosyncline in the locality of the present southeastern Caucasus. The region of subsidence and the region of the rising Caucasus were situated side by side. A zone of uninterrupted struggle between land and sea, where transgression alternated with regression, was formed. It was a zone in which, under favorable conditions, strata rich in organic matter could be deposited which could prepare the way for the formation of oil-bearing series, or of mother beds, serving as oil-generating material. Several oil-bearing series were deposited here: (1) bituminous shales and oil shales of the Sumgait series; (2) the Brown Kown, which is a typical sapropelitic rock (it contains intercalations of oil shales); (3) Maikop series; (4) *Spirialis* beds, and (5) all the Diatom series, which contain, besides diatoms, abundant fish remains.

All these series have a distinct sapropelitic character, which originated under conditions of littoral marine deposits. The active process of erosion of the near-by Caucasian mainland aided the speedy accumulation of deposits, and their speedy burial and descent to deeper and deeper zones. This process was accompanied by evolution of heat and by increasing pressure, which in turn aided the process of oil and gas formation, along with the action of the anaerobic bacteria. As the result of all these factors, oil was formed in the strata. If molecular movements caused by the action of capillary forces are discounted, oil could remain in this diffused state for a long period, to the very beginning of the orogenic processes.

Furthermore, these anticlines produced unevenness of the sea bottom, as a result of which followed unequal accumulation of deposits. It was greater in the synclinal troughs into which deposits slid from the anticlinal arches. The distance from the shore also influenced the rate of accumulation of deposits. Thus originated the zones of unequally loaded strata. In the course of the successive orogenic phases, this process was greatly intensified and the difference between the zones of high and low pressure became more and more marked. The eastern Caucasian orogenic phase, which took place after the depositing of the Pontian strata, played an important part in this process. As a result of this phase, no doubt, a considerable portion of the local geosyncline became dry land, which apparently occupied not less than half of the present Caspian Sea. It is possible that the sea retreated to the deeper sections, where a constant formation of deposits proceeded. A hint of this is given by the evidence of conformity of the Pontian and the Productive series in the Djorat district. In any case, during the deposition of some of the more characteristic horizons of

the Productive series which have been incorrectly described as "Breaks," the Pontian mainland by this time had been subjected to active erosion and had been carried away to the basin in which the Productive series was being deposited. The deposits accumulated so rapidly that the basin became overfilled and a period of continental regime set in. It was under these conditions that the whole Middle division of the Productive series developed, with its thick sand beds, which in places resemble the "barkhan" (dune) sands, and with its globular lumps of clay, to which D. V. Golubiatnikov attached exceptional stratigraphic importance as proofs of desert conditions then prevailing. These rounded lumps, like the trigonal pebbles which are found in the conglomerate-like sandstones of the "Breaks," serve as an excellent key horizon.

The presence of *Helix* in the sands of this section confirms Golubiatnikov's thesis. The lithologic character of the Productive series is not the same throughout the regions of its distribution.

In the Balakhany-Sabunchy-Ramany oil-field district, sand beds constitute 75 per cent of the Productive series, in the Atashka section 60 per cent, and in the Puta section 40 per cent. After the deposition of the Productive series, the differentiation of strata with respect to their loading proceeded still further. During the extensive Aktchagil marine transgression, which embraced vast areas in the south and southeast parts of European Russia, this uneven loading began to influence the local tectonics. Plastic argillaceous masses of Maikop and *Spirialis* beds became submerged to a great depth. A series 2,250–2,500 meters thick covered the Diatom beds. If the specific gravity of the strata was 2.7, there was a pressure of approximately 600 atmospheres. The Maikop series was covered by a series 3,000 meters thick, which is equivalent to a pressure of more than 800 atmospheres and a temperature of 100°C. In the Aktchagil stage, therefore, diapiric domes, mud volcanoes, and oil-bearing strata began to be formed. Thick layers of argillaceous breccia, 10–15 meters in depth, are to be found among the Aktchagil deposits in central Kabristan. These strata have been mistaken by some geologists for tectonic inter-strata breccia. They attribute the origin of this breccia to the so-called "disharmonious" folds, which presuppose a rift and a sliding of rock complexes against one another on a gigantic scale, embracing enormous areas of the size of the Kabristan Steppes or of the Apsheron Peninsula. Under the enormous pressures involved in such sliding, the strata of the sliding mass will be crushed and transformed to breccia. In the case of disjunctive faulting, the moving masses will be driven against the anticlinal arches and, in successive movements, the breccia

will become imbedded in the form of large intrusive masses in the crushed normal strata of the folds.

The tendency was to impart to the "tectonic breccia," or to "tectonites," as they are now being briefly called, the significance of regional character. Disjunctive faulting gave rise to enormous masses of breccia, which are now found in the region of development of mud volcanoes. This tectonic breccia, which has been classified in various types, such as "breccia α," and "breccia β," served and still serves as the material for the formation of volcanic breccia, extruded by mud volcanoes.

The area, occupied at present by mud volcanoes, consists of tectonic breccia, which has spread over an enormous area and to a great depth. According to the adherents of the "disharmonious fold" theory, prospective drilling in these localities would lead one to enormously deep pits containing breccia exclusively.

A closer investigation revealed, in the cementing substances of the "tectonic" breccia, fauna of the Aktchagil stage, which is the evidence of its submarine deposition. Breccia with faunal characteristics of definite strata was found in the Lower Apsheron and contained typical fauna of this horizon. At the other end of the Caucasus, on the Taman Peninsula, the writer found Pontian fauna in the volcanic breccia at the base of a shore escarpment, not far from the now active Tisdar mud volcano. What do these facts signify? First, volcanic breccia does not consist of great imbedded intrusive masses, but is a deposit formed by extrusions of mud volcanoes of a submarine or of a continental type, but in any case located in the sea. Mud volcanoes are a common occurrence in the Caspian Sea. The islands of the Baku Archipelago (Loss, Duvan, Oblivnoi, Gliniany, Svinoi, and others) are now active mud volcanoes which cover with their ejections not only the islands, but also the adjacent sea areas. Kumani Island, which emerges and is submerged by turns, is very interesting in this respect. It is an ordinary mud volcano which first appeared in 1861 and was described by Abich. Appearances and disappearances of this island are explained by accumulations of ejected volcanic mud which is then fairly rapidly washed away by the waves of the sea. Submarine eruptions of mud volcanoes occurred also in the Azov Sea along the northern shores of the Taman Peninsula, and have been also mentioned in Abich's works. Secondly, these facts point to the beginning of the activity of mud volcanoes far back in Aktchagil time. Intercalations of volcanic ash in these beds confirm such contention.

Since the origin of most mud volcanoes is connected with the formation of diapiric folds, it is obvious that some diapiric domes had

already appeared in Aktchagil time in many places in Kabristan. At that time, however, they had not risen above the sea-level.

Evidently by this time the process of differentiation of high- and low-pressure zones had progressed so far that the plastic argillaceous masses, subjected to enormous pressure, moved along the lines of least resistance, that is, toward the arches of the folds, which, as was previously explained, originated by crustal shortening under the action of tangential stresses.

Thus began the squeezing out of these masses upward through the strata of more recent origin; that is, thus began the formation of diapiric structures and their appearance on the arches of the folds. As soon as this process set in, a flow of water and gas began, followed by oil, toward the core of the fold, that is, toward the most elevated and the least compact part of the structure.

Thus began the rising and the accumulation of the three substances which determined the development of mud volcanoes and oil fields. Gas and water, as the most mobile of the three, were the first to rush up to the core. Water softened the strata of the cores; under the influence of gas pressure it was forced upward and issued in the form of gaseous springs at the top of diapiric structures. If the flow of gas was abundant, it had not time enough for exit and accumulated in great quantities within the core, thus giving rise to enormous pressures.

The resulting pressure led to the explosion of gas and to its ejection. Forcing its way in a powerful stream, it swept with it pieces of core and adjoining strata destroyed by the force of explosion. In most cases the explosion was accompanied by ignition of the gases, producing great pillars of fire sometimes more than 300 meters high, and by eruption of streams of mud. According to data supplied by the Baku seismograph station, an eruption took place on October 1, 1927, on the site of the submarine mud volcano of Kumani, 12 miles south of Hog Island. As in 1861, this eruption resulted in the reappearance of the island. The eruption was accompanied by underground shocks, 41 of which were recorded. One can judge the force of gas eruptions by the enormous rocks which were ejected from the crater of this volcano.

A thick covering layer of volcanic breccia accumulates on the slopes of the mud volcanoes situated on the dry land. Some authors regarded this volcanic breccia as *tectonic* breccia, serving as material for the formation of volcanic breccia. The latter, according to them, has a slightly different structure and its distribution is limited.

Oil wells drilled on the slopes of Lok-Batan through the covering

layer of mud breccia, which is 30–40 meters thick, revealed the presence under the breccia of the normal strata of the Productive series. Shallow tests have shown that the crater and the apophyses extending from it occupy a comparatively small area.

The results of prospecting on Lok-Batan refute, therefore, the hypothesis of "disharmonious folds" and the contention that they generate "tectonites."

The foregoing discussion shows how mud volcanoes were formed. The study of the diapiric structures on the Apsheron Peninsula shows that, in its upward movement, the core not only becomes itself deformed and crushed, but also rifts the surrounding strata, producing thereby a dense network of fissures along which the mingling of the strata takes place. These fissures serve as the paths along which oil and gas flow upward toward the core and accumulate in the porous strata surrounding it. Besides the gas, oil makes its way here from its source beds under the influence of the squeezing action of the vertical pressure, and also as a result of capillary attraction. Consequently, such a migration of oil and gas can take place only where gas- and oil-producing strata are located at a depth which assures the necessary temperature and pressure and where, at the same time, mother beds come into contact with the piercing core.

Two circumstances could help to retain oil in the porous strata surrounding the core: (1) the presence of a roof of impervious rocks in the form of a thick argillaceous series (in the Baku oil fields, this part is played by the Aktchagil clay and by the lower section of the Apsheron strata); and (2) the sealing of oil-bearing horizons by the rise of the piercing core.

In reviewing the relation of diapiric structures to mud volcanism and to the formation of oil deposits, it is seen that some of these structures contain neither oil nor gas, and no mud volcanoes are situated on them. These are *barren* diapiric structures. Others are connected only with mud volcanoes. The third group comprises both mud volcanoes and oil-bearing fields. Also, there are tectonic forms in which only oil is produced; and, lastly, there are structures which yield only dry gas.

1. There are many examples of barren diapiric structures. They are a common occurrence in northern Kabristan. In the writer's opinion this is due to the fact that here the principal oil-originating series lie near the surface. They form either part of distant flanks of the fold, or the adjacent synclines. In the preceding geologic ages they were not submerged deeply enough under the bottom of the sea to be

under conditions favorable for the final transformation of their organic matter into oil.

2. The connection of diapiric structures only with the appearance of mud volcanism is a fairly frequent occurrence. Such structures, likewise, are chiefly found in northern Kabristan, where mud volcanoes are situated on diapiric structures formed by Mesozoic strata. Here the deep Mesozoic levels could supply the structures only with gas. Accordingly, in the Apsheron Peninsula and especially in the Kabristan Steppes are mud volcanoes in whose proximity no visible indication of petroleum is to be observed, in spite of the fact that they are located on very recent formations. Tourogai and Kyanisa-Dag are examples of this nature. Their oil-producing capacity is unknown for the sole reason that they have not been explored. Prior to 1913, the Lok-Batan mud volcano was looked upon as one of this kind. In the space of only one year, the wealth of its oil deposits has been proved by large gushers. The lessons derived from Lok-Batan have completely altered the approach to the exploration of mud volcanoes of the type of Tourogai, Kyanisa-Dag, and others.

3. The combined presence in diapiric structures of mud volcanoes in the center and of oil fields on the periphery needs no explanation, as the preceding matter sufficiently explains this remarkable combination. Examples of such combinations are well known: the famous Balakhany-Sabunchy-Ramany oil fields, Bibi-Eibat (a cryptic diapiric structure), Lok-Batan, Puta, and others.

4. The presence of structures containing only oil (Surakhany, Kara-Chukhur, Kala, and others) can be explained, in the writer's opinion, by insufficiently developed diapirism. In such cases the piercing core has only partly raised the overlying younger strata. It has prepared a good storage for oil, gas, and water. But the pressure of the accumulated gas is not sufficient to overcome the weight of the whole mass resting over the producing bed. Here the gases can find an outlet only through the fissures, and exit either in the form of dry jets, such as the one over which, at Surakhany, the Fireworshippers built their temple of Eternal Fire, or else they find an outlet in the form of gaseous mineral-water springs. But when man, with the help of his science, breaks into these virginal deposits, and only partly releases the pressure of the entrapped gas, there is an eruption of gas and mud not at all different in its character and in force from the eruptions of natural mud volcanoes.

5. Explanation of dry gas seeps on the summits of diapiric structures can be given by the science of hydrology, which can account for

the reasons why water could not penetrate into certain diapiric structures.

Only by the absence of this basic factor in the cores of some diapiric structures can the exudation of only dry gas be explained. Mount Atashka (Eternal Fires) serves as an example of exudation of gas in the form of a jet at an altitude of about 275 meters above sea-level.

In the extrusions of mud volcanoes located in recent Pliocene formations, are commonly found pieces of rocks belonging not only to the Lower Tertiary age, but also to some older Mesozoic strata. Evidently in the process of piercing, the core has carried along parts of some older strata, which served to feed the diapiric structure with gas. The flow of gas from the Mesozoic gas-bearing levels had undoubtedly influenced the formation of oil fields and the quality of their oil within the limits of the southeastern Caucasus.

The formation of mud volcanoes and of oil fields, which began in the Aktchagil stage, continued during the deposition of the Apsheron strata. At any rate, in the Lower Apsheron in the vicinity of the still active Utalgi volcano, layers of volcanic breccia were found in the cementing substance of which the young Soviet scientist, Mulaev, discovered *Dreissensia rostriformis*.

The last orogenic phase, which took place at the end of Pliocene and at the beginning of Pleistocene time, completed the major tectonic features of the southeastern Caucasus. After this period part of the region was covered by the transgression of the Ancient Caspian, which left its deposits in the form of terraces of different height. In some places lower Ancient Caspian deposits are found at an elevation of 200 meters above sea-level. This is a result of the epeirogenic movements. But even at that time diapiric tectonics continued, which strongly emphasizes its limited localized significance. In 1914 the writer happened to come across two highly interesting facts. On the summit of Mount Boz-Dag (northern) at an elevation of about 250 meters, were calcareous shaly strata with the fauna of the Ancient Caspian deposits. These strata were tilted vertically upward at a dip of 90°.

This dislocation is local and is undoubtedly connected with the uplifting of the piercing core which is composed here of White Kown strata, in which one of the huge mud volcanoes of the Apsheron Peninsula is situated.

In the same year the writer discovered another interesting fact at the foot of the north limb of the Husdeck anticlinal elevation, which extends in the latitudinal direction from the Huzdeck Station far toward the west up to Kown Mountain. Here, at the surface of contact

of one of the Ancient Caspian terraces with the piercing core composed of the Kown series, calcareous shaly strata, dipping very sharply northward, are found. This steep angle quickly flattens and the layers become horizontal. Also here, the steep dip of the terrace edges can be explained only by the uplifting of the core of the fold. Such examples are not rare.

The uplifting of the cores of diapiric folds continues at present. Two accurate surveys, made in 1912 and repeated in 1928, show that in some parts of the Apsheron Peninsula uplifting is going on, whereas in others there is subsidence. For instance, during this interval of time the summit of Mount Bog-Boga, which is the core of the Balakhany-Sabunchy-Ramany fold, has been raised more than 3 meters.

The most convincing data, however, have been obtained by observing fluctuations of the Caspian sea-level. The Caspian is an enclosed basin with an area of approximately 400,000 square kilometers and is therefore not affected by the oceans. Its fluctuations can not be explained by meteorological fluctuations connected with climatic changes, and must be explained by those dynamic processes which change the face of the earth.

Many small islands rise above sea-level to be later washed away by the waves—for example, Kumani. The legends of sunken cities and villages are not mere legends, but facts. This is proved by the remarkable 700-year old history of the small Karavanserai in the Bay of Baku. Remains of this Karavanserai, or, to be more exact, a little fortification, are visible in the southwestern part of the bay. They consist of seven or eight towers, connected by walls. This structure was built on the mainland about 1135 A.D.

In 1135 the shore of the bay extended far toward the east and joined the islands known to-day as Nargen and Wulf. Historical documents state that in the beginning of the 14th century (in 1306) the entire southern Caspian was agitated by a strong earthquake as a result of which the city of Abeschun was destroyed and submerged into the Astrabad Strait. At the same time Baku was partially inundated so that the water level reached the Royal Mosque, which is still in existence to-day. Then followed a lowering of the sea-level and in 1623 the towers of the Karavanserai for the first time began to emerge from the sea. The whole history of this Karavanserai shows that in the environs of Baku the Caspian has risen during the last 8 centuries more than 20 meters, and then by a series of successive subsidences had reached its original level, that is, it has described a practically complete cycle of fluctuations around the same level.

All these facts, taken together with the unceasing activities of mud

volcanoes, and the violent earthquakes in the southern part of the Caspian as well as in the Shemakha district, are evidences of epeirogenic fluctuations and further displacement of the cores in the diapiric folds. The latter phenomena are connected not only with the structure of the dry land in the zone of the southeastern submergence of the Caucasus, but also with the structure of the Caspian Sea bottom, which is divided in two by a submarine saddle extending in the direction of the Apsheron Peninsula and Krasnovodsk. The north part, opposite Derbent, is approximately 768 meters deep and the south part is 945 meters deep opposite Lenkoran, whereas the depth of the saddle is only 100–150 meters. The fluctuations of the bottom level in these great synclinal basins affect the level of the Caspian Sea, as well as the local tectonics depending on the vertical pressure.

DISCUSSION

ARNOLD HEIM, Zurich, Switzerland: Petroleum geology with its ample records of deep borings becomes of the highest importance for our knowledge of tectonics in general. A most remarkable example is the one presented by the Russian petroleum geologists and I. M. Goubkin's paper on the eastern Caucasus.

Formerly, it was generally considered that normally after sedimentation follows orogenesis, then erosion, this being one cycle. Now we see that these phenomena may work *simultaneously*, even over such long periods as the whole Cenozoic, *intensely affecting each other*.

Folding by lateral compression below the sea (formation of submarine breccias!) influences the distribution of sediments, the anticlinal parts receiving so little sedimentary cover that further compression results in diapirs, combined and influenced or not by erosion and isostatic readjustments.

Folding and other dislocation having frequently occurred without relation to surface relief (under water or at depths below 30 kilometers), it is proposed to eliminate or restrict the word orogenesis or orogeny, and to use Haarman's term *tectogenesis* or *tectogeny* in preference.

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Olin G. Bell, Herschel H. Cooper, Phil F. Martyn

Luther B. Smith, Jr., Tyler, Tex.
Albert E. Oldham, W. L. Goldston, Jr., Willis Storm

NINETEENTH ANNUAL MEETING
THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BAKER HOTEL, DALLAS, TEXAS, MARCH 22–24, 1934

The nineteenth annual meeting was the fourth Association meeting held in Dallas. The first and second Dallas meetings were in 1919 and 1920. At the third Dallas meeting in 1926 such a high mark of entertainment and hospitality was attained that there was some wonder about the possibility of equalling that record in 1934. It is probable, however, that those who attended both meetings will agree that the Dallas geologists have again added to their reputation as enviable hosts—and hostesses.

Wednesday, noted on the program as a pre-convention day, was full of convention activity: committee meetings in the banquet rooms at the north end of the mezzanine; exhibitors setting up their equipment displays in the lounge at the south end near the ball room where operators were trying out the projectors and microphones for the technical papers; noisy, informal reunions being staged around the information booth in the crowded lobby; and altogether, an exceptionally large and early registration of members and guests made it appear as if the convention were in full swing. Perhaps this boom-like scene inspired the *Outcrop* reporter, looking up at the two national flags guarding the A.A.P.G. banner on the mezzanine railing, to use the lead in Thursday's issue, "Dallas Center Oil Industry!"

Early Thursday morning, members were greeted before leaving their hotel rooms, by the appearance of *The Dallas Outcrop*, the daily review of the convention. This 5-column, 8-page newspaper, the "Local expression of the 19th annual convention," was successfully edited and published each morning as the fruition of long-laid plans and almost sleepless work of editors Sam Aronson and Chester A. Hammill and their associates. The *Outcrop* appeared in three "Exposures" and was such a live feature and such a valuable record of the whole meeting that the executive committee decided to send copies to members who could not attend.

The official welcome to Dallas was given Thursday morning in the Crystal Ball Room of the Baker Hotel by the representative of the Dallas Chamber of Commerce, J. Ben Critz, introduced by W. E. Wrather, a former president of the Association, representing the Dallas geologists. President Frank R. Clark responded with the presidential address, "The New Challenge." Robert T. Hill, veteran and honored member from Texas, presented the first paper on the technical program.

The number of papers orally delivered was restricted so that each author had plenty of time with a sufficient period left for discussion. Thus, only 18 papers were presented at the full 3-day general sessions. Another innovation that worked with great satisfaction was the excellent operation of the lapel microphones on the speakers and the sound amplifiers at the sides and at the back of the room, so that all could hear with comfort. Illustrations were restricted to lantern slides which were projected through a powerful lens from the balcony in the back of the room, without disturbance to those listening to the speaker. The bulletin board at the entrance of the auditorium was constantly posted, an arrow indicating the current subject and author. This announcement board, a special piece of cabinet work, was presented to the Association by the Dallas Petroleum Geologists.

Some members recalled the 1926 convention committee's gift to the Association,—the flags and the red, white, and blue pick-and-hammer banner hanging in the lobby in 1934. In truth, after intervening years of ups and downs, many sensed a feeling of youth and optimism like the enthusiastic and vigorous spirit that pervaded that 1926 meeting, when plans were in the making for national headquarters and greater work for the Association.

It seems certain that oral, ocular, and gastronomic delights are still considered essentials of a successful convention. Entertainment was provided men, women, and children in customary Dallas fashion. And, judged by attendance, a good time was had by all. Tickets sold for the banquet, floor show, and dance on Thursday night numbered 1,040; the Ball Room was full and the banqueters happy, and the Peacock Terrace likewise.

At such a scene when the bare expanse of ball room floor awaits mid glaring expectancy the entrance of the performers, the most insignificant occurrence or the most innocent individual who may chance across the spotlight is set forth with exaggerated prominence and caught by the expectant crowd in a flood of spontaneous hilarity. To pick only two of the many who moved across that no-man's land may seem like favoritism but these two clicked: (1) Paul Weaver, testing his ability in stepping the shortest distance between two points without deviation or wobble; (2) Julius Fohs, coming into focus by accident, and alone, with frantic modesty, and very visible suffering, attempting to flee the thundering applause he had unwittingly brought forth.

A pre-convention statement asserted that the ladies would be entertained and amused. No post-convention complaints or denials have been entered. There was a style show offering "the latest from Paris," and we are told (we were not present) that phrase contained as much fact as fiction. A "get-acquainted" tea, also at the department store, and Little Theatre party completed Thursday for the ladies. On Friday there was a delightful luncheon amid spring flowers in the Gold Room of the Adolphus Hotel Roof.

The field trips planned for Saturday were somewhat curtailed because of rain, but about 20 people went to the Grand Saline salt mine and the Van oil field.

Golf Tournament

In Dallas the Bostick golf trophy was again in the home town of its donor. J. Wallace Bostick presented this beautiful prize to the Association at the time of the 1926 Dallas meeting for the development of closer friendship and good fellowship. The 1934 tournament was held at the Brook Hollow Golf Club. Thirty members and 24 invited guests participated. Winning honors under the rules of the trophy went to H. A. Hemphill (member), of San Angelo, Texas, and to Cherry Oldham (guest), of Dallas. Mr. Hemphill's name is engraved on the base of the trophy kept at Association headquarters and Mr. Oldham's name is engraved there and on the small Bostick cup which is his prize. The local committee awarded additional prizes as here shown.

First Flight		*Gross*	*Handicap*	*Net*	*Prizes*
Low net	Cherry Oldham (guest)	80	7	73	Handbag
Second prize low net	H. A. Hemphill (member)	82	8	74	Set wood clubs
Best selected 9 holes	Elfred Beck (member)	88	11	77	Set wood clubs

Second Flight					
Low net	T. E. Swigart (member)	84	14	70	Set wood clubs
Second prize low net	D. M. Stacy (member)	87	15	72	Golf bag
Best selected 9 holes	Dr. L. Hudson (guest)	98	21	77	Golf bag
Third Flight					
Low net	L. M. Dabney (guest)	90	20	70	Umbrella
Second prize low net	F. Brinegar (guest)	101	23	78	Special niblick
Best selected 9 holes	J. E. Elliot (member)	107	24	83	Umbrella

Division of Paleontology and Mineralogy

The eighth annual meeting of the Society of Economic Paleontologists and Mineralogists was held on Friday. Twenty-seven papers were scheduled. The new officers are: president, Norman L. Thomas, Fort Worth, Texas; vice-president, Merle C. Israelsky, Houston, Texas; secretary-treasurer, Gayle Scott, Fort Worth, Texas; editor, Raymond C. Moore, Lawrence, Kansas.

Division of Geophysics

The fifth annual meeting of the Society of Petroleum Geophysicists was held on Friday. Six papers were presented. The new officers are: president, E. E. Rosaire, Houston, Texas; vice-president, Frank Goldstone, Houston, Texas; secretary-treasurer, Bela Hubbard, Tulsa, Oklahoma; editor, B. B. Weatherby, Tulsa, Oklahoma.

Convention Registration

Total registration was 1,400, classified as follows: 2 honorary members, 548 members, 94 associates, 329 non-member men, and 427 non-member women.

Executive Committee

Frank R. Clark, chairman; William B. Heroy, secretary; Frederic H. Lahee, George Sawtelle, L. C. Snider.

Dallas Petroleum Geologists

F. E. Heath, chairman; J. C. Karcher, vice-chairman; Charles B. Carpenter, secretary-treasurer.

Dallas Committees

General.—Clyde M. Bennett, chairman; Chester A. Hammill, vice-chairman; J. Wallace Bostick, Robert T. Hill, R. S. McFarland, Leon J. Pepperberg, Leon F. Russ, Ellis W. Shuler, W. E. Wrather.

Program.—F. H. Lahee, chairman; George E. Dorsey, H. B. Hill, Eugene McDermott, J. A. Waters.

Registration.—F. E. Heath, chairman; Charles B. Carpenter, T. K. Knox, L. C. Smith, V. V. Waite, W. E. Winn.

Entertainment.—Joseph M. Wilson, chairman; D. J. Crawford, Frederick Frei, Frank Kendrick, P. W. McFarland, L. W. Orynski, Heath M. Robinson.

Equipment.—George E. Dorsey, chairman; George E. Burton, Charles B. Carpenter, Fred E. Joekel, Garrett Kemp, H. M. Law, Eugene McDermott.

Finance.—R. B. Whitehead, chairman; J. Wallace Bostick, D. Harold Byrd, E. B. Germany, Henry J. Hawley, Edwin B. Hopkins, J. C. Karcher, R. S. McFarland.

Publicity.—S. M. Aronson, chairman; W. Grant Blanchard, Jr., W. W. Clawson, Chester A. Hammill, P. W. McFarland, K. C. Sclater.

Trips.—D. J. Crawford, chairman; Norman W. Brillhart, John Doering, Jack Frost, J. W. Minton, W. A. Reiter, Gustav Wade.

Golf.—Edwin B. Hopkins, chairman; W. Grant Blanchard, Jr., P. W. McFarland, Carlton Meredith, Heath M. Robinson.

Reception.—L. W. Orynski, chairman; E. B. Germany, Frank Kendrick, T. K. Knox, Leon F. Russ, Joseph M. Wilson.

LADIES ENTERTAINMENT

In general charge.—Leonard W. Orynski

Reception.—Mrs. Frederic H. Lahee, chairman; Mrs. Chester A. Hammill, co-chairman. Assisted by: Mrs. Harry B. Hill, Mrs. Garrett Kemp, Mrs. T. K. Knox, Mrs. H. M. Law, Mrs. C. R. Nichols, Mrs. K. C. Sclater, Mrs. Lee C. Smith, Mrs. J. A. Waters.

Style show.—Mrs. W. E. Wrather, chairman; Mrs. Joseph M. Wilson, co-chairman. Assisted by: Mrs. Francis E. Heath, Mrs. Carlton Meredith, Mrs. P. W. McFarland, Mrs. J. W. Minton, Mrs. Melbert Schwartz.

"Get-Acquainted" tea.—Mrs. John C. Karcher, chairman; Mrs. Russell S. McFarland, co-chairman. Presiding at the tea table: Mrs. Frank Rinker Clark and Mrs. Clyde M. Bennett. Assisted by: Mrs. W. Grant Blanchard, Jr., Mrs. J. Wallace Bostick, Mrs. Charles B. Carpenter, Mrs. Frank Kendrick, Mrs. J. W. Lewis, Mrs. Ellis W. Shuler, Mrs. W. E. Winn.

Luncheon.—Mrs. Leonard W. Orynski, chairman; Mrs. Leon F. Russ, co-chairman. Assisted by: Mrs. Sam M. Aronson, Mrs. William W. Clawson, Mrs. David J. Crawford, Mrs. Frederick Frei, Mrs. E. B. Germany, Mrs. Henry J. Hawley, Mrs. Gustav Wade.

Little Theatre Party.—Mrs. Leon J. Pepperberg, chairman; Mrs. Edwin B. Hopkins, co-chairman. Assisted by: Mrs. George E. Burton, Mrs. Fred E. Joekel, Mrs. Eugene McDermott, Mrs. R. A. Stehr, Mrs. V. V. Waite.

SCHEDULE OF EVENTS

(All meetings and sessions on mezzanine, Baker Hotel, unless otherwise announced. Admission to technical sessions, free. Admission to all entertainment by ticket only.)

TUESDAY, MARCH 20 (PRE-CONVENTION)

7:00 P.M. Executive committee, Frank Rinker Clark, chairman

WEDNESDAY, MARCH 21 (PRE-CONVENTION)

9:00 A.M. Registration
9:00 A.M. Committee on applications of geology, Frederic H. Lahee, chairman. Private Dining Room 4
9:00 A.M. Committee on geologic names and correlations, M. G. Cheney, chairman. Private Dining Room 5

11:00 A.M. Business meeting, research committee, Donald C. Barton, chairman. Private Dining Room 4
2:00 P.M. General business committee, Russell S. Knappen, chairman. Private Dining Room 1
6:15 P.M. Informal dinner, research committee, followed by round table discussion of "Time of Migration of Petroleum with Special Reference to the Age of Petroliferous Structures and to Levorsen's Studies in Paleogeology." Open to non-members of the research committee, who can contribute pertinently to the discussion. Private Dining Room 1

THURSDAY, MARCH 22 (CONVENTION)

7:30 A.M. Registration, lobby floor
10:00 A.M. Address of welcome, response, and presidential address. Crystal Ball Room
10:45 A.M. General technical session. Crystal Ball Room
12:30 P.M. College and fraternity luncheons
2:00 P.M. General technical session. Crystal Ball Room
3:00 P.M. Style show for visiting ladies, French Salon, Neiman-Marcus store, followed by:
4:00 P.M. "Get-Acquainted" tea for the ladies at same place
4:45 P.M. Announcements, nomination of officers, appointment of committees. Crystal Ball Room
8:00 P.M. Smoker. Peacock Terrace, Baker Hotel
8:30 P.M. Ladies theatre party, "Biography." by S. N. Behrman, The Little Theatre of Dallas

FRIDAY, MARCH 23 (CONVENTION)

8:00 A.M. Ballot box open, Association booth
9:00 A.M. General technical session. Crystal Ball Room
9:00 A.M. Technical session, Society of Petroleum Paleontologists and Mineralogists. South Room, Peacock Terrace, Baker Hotel
9:00 A.M. Tehnical session, Society of Petroleum Geophysicists. Main Auditorium, 17th floor, Dallas Power & Light Building
12:00 A.M. Ladies luncheon. Gold Room, Adolphus Hotel
12:30 P.M. Paleontologists' luncheon. W. H. Twenhofel, speaker. Private Dining Room 1
12:30 P.M. Geophysicsts' luncheon, annual business meeting. Private Dining Rooms 5 and 6
12:30 P.M. College and fraternity luncheons
1:00 P.M. Golf tournament for Bostick Cup, Brook Hollow Country Club
2:00 P.M. General technical session. Crystal Ball Room
2:00 P.M. Technical session, Society of Economic Paleontologists and Mineralogists. South Room, Peacock Terrace, Baker Hotel
2:00 P.M. Technical session, Society of Petroleum Geophysicists. Main Auditorium, 17th floor, Dallas Power & Light Building
4:00 P.M. Annual business meeting, Society of Economic Paleontologists and Mineralogists. South Room, Peacock Terrace, Baker Hotel
7:30 P.M. Banquet and dance. Crystal Ball Room and Peacock Terrace

SATURDAY, MARCH 24 (CONVENTION)

9:00 A.M. Nineteenth annual business meeting. Announcement of elections. Crystal Ball Room
10:00 A.M. Executives committees, joint meeting 1933 and 1934 officers
10:00 A.M. General technical session. Crystal Ball Room
2:00 P.M. General technical session. Crystal Ball Room

SATURDAY, MARCH 24 (TRIPS)

12:30 P.M. Local outcrops of the Woodbine and associated formations. Return to Dallas, Saturday afternoon
12:30 P.M. Grand Saline salt mine and Van oil field. Return to Dallas, Saturday night

12:30 P.M. Grand Saline salt mine and van oil field. Night at Longview. Sunday, East Texas oil field. Return to Dallas, Sunday afternoon

1:00 P.M. Navarro and Midway outcrops near Corsicana and Mexia, under auspices Society of Economic Paleontologists and Mineralogists. Night at Corsicana and return to Dallas from Mexia, Sunday afternoon

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TECHNICAL PROGRAM

I. GENERAL ASSOCIATION PAPERS TO BE PRESENTED ORALLY

1. ROBERT T. HILL, The Texas Cretaceous Continued
2. S. A. THOMPSON, The Fredericksburg Division of the Lower Cretaceous with Special Reference to North-Central Texas
3. E. DEGOLYER, Notes on the Development of the Technique of Oil Finding
4. FRANK W. MICHAUX, JR., A Comparison of the Structural and Reservoir Conditions of the Conroe and Tomball Oil Fields
5. L. L. NETTLETON, Fluid Mechanics of Salt Domes
6. HUGH D. MISER, The Carboniferous Rocks of the Ouachita Mountains
7. M. G. CHENEY, Well-Spacing Problems Involved in Petroleum Geology
8. C. DWIGHT AVERY and J. CHARLES MILLER, The Relationship of Geology to Unit Operation of Oil and Gas Fields Involving Government Lands
9. O. E. MEINZER, Movements of Underground Water
10. ORVAL L. BRACE, Factors Governing the Estimation of Recoverable Oil Reserves in Sand Fields
11. J. S. HUDNALL, The East Texas Field
12. ED. W. OWEN and DAVID J. CRAWFORD, Fault Systems of the Gulf Coastal Plain
13. IRA H. CRAM, A Study of Subsurface Faults in Oklahoma
14. THEODORE A. LINK, The Petroleum Industry Exhibit at the Century of Progress, Chicago, 1933.
15. N. W. BASS, Origin of the "Bartlesville" Shoestring Sands of Kansas
16. PARKER D. TRASK and H. E. HAMMAR, Preliminary Study of Source Beds in the Mesozoic Rocks on the West Side of the Sacramento Valley, California
17. SHEPARD W. LOWMAN, Cherokee Structural History of Oklahoma
18. Recent Development in Western Oklahoma
    (1) R. W. BRAUCHLI, The Edmond Pool, Oklahoma County, Oklahoma
    (2) T. M. RAGSDALE, The Chandler Pool and West Extension of Lincoln County, Oklahoma
    (3) H. S. THOMAS, The Lucien Pool
    (4) G. C. MADDOX, The Crescent Pool
    (5) GLENN GRIMES, The Tatums Pool
    (6) E. I. THOMPSON, Wildcats in Western Oklahoma

II. GENERAL ASSOCIATION PAPERS TO BE PRESENTED BY TITLE

1. O. C. WHEELER, Infantas and La Cira Oil Fields of Colombia
2. SYLVAIN PIRSON, Oil Possibilities of Belgium and the Belgian Congo
3. J. S. IRWIN, Geology and Oil Resources of Cutbank Field, Montana
4. T. A. HENDRICKS and C. B. READ, Correlation of the Pennsylvanian Strata in the Arkansas and Oklahoma Coal Fields
5. C. E. ERDMANN, Geology of Whitlash Dome, Liberty County, Montana
6. DAVID WHITE, The Age of the Jackfork and Stanley Formations in the Ouachita Mountains, as Indicated by Plants
7. BEN H. PARKER, The Cretaceous Geosyncline of the Rocky Mountain Region
8. J. HARLAN JOHNSON, Pennsylvanian and Permian of Colorado
9. W. C. BLACKBURN, The Hilbig Oil Field, Bastrop County, Texas
10. J. LAWRENCE MUIR, The Anhydrite-Gypsum Problem of the Blaine Formation, Oklahoma
11. F. W. FLOYD and D. C. NUFER, Stratigraphy in Ardmore Area, Oklahoma
12. WALTER B. LANG, Permian Ice Crystal Markings
13. WALTER A. VER WIEBE, Geology of Alaskan Oil Fields
14. THEODORE A. LINK, Structure of the Turner Valley Gas and Oil Field, Alberta

III. PALEONTOLOGY AND MINERALOGY

TEXAS AND LOUISIANA TERTIARY

1. C. I. ALEXANDER, *Ostracoda* of the Midway of Texas
2. R. W. HARRIS, Wilcox and Claiborne Ostracodes from Gulf Coast of United States
3. MERLE C. ISRAELSKY, Tentative Foraminiferal Zonation of the Claiborne
4. H. B. STENZEL, Sparta-Crockett Transition on Brazos River, Texas
5. HENRY V. HOWE, Sabine Eocene Ostracodes
6. H. B. STENZEL, Use of Small Macrofossils in Correlation
7. M. A. HANNA and D. W. GRAVELL, Larger *Foraminifera* from the Moody's Branch Marl, Jackson Eocene of Texas, Louisiana, and Mississippi
8. M. A. HANNA and D. W. GRAVELL, Zonation of Oligocene of Texas, Louisiana, and Mississippi
9. R. W. HARRIS and V. L. FROST, Jackson-Oligocene *Ostracoda* from Gulf Coast
10. HENRY V. HOWE, *Bitubulogenerina*, a New Eocene Genus of *Foraminifera*
11. HENRY V. HOWE, *Bairdia Subdeltoidea* (Munster) in American Tertiary
12. PAUL P. GOUDKOFF, Formation of Upper Miocene of San Joaquin Valley, California
13. A. J. TIEJE, Progress Account of Committee on Revision of Miocene Nomenclature in California
14. HELEN JEANNE PLUMMER, Diagnostic *Foraminifera* of Kincaid and Wills Point Formations in Texas

GENERAL

1. R. W. HARRIS and DAN JONES, Some New Species of Ostracodes and Conodonts from Francis Formation of Oklahoma
2. E. B. BRANSON and M. G. MEHL, Progress in Investigation of Conodonts at the University of Missouri
3. J. A. CUSHMAN, Value of Study of Type Specimens of *Foraminifera*
4. CHARLES E. DECKER, Graptolites of Sylvan Shale of Oklahoma
5. R. C. MOORE, Mississippian-Pennsylvanian Boundary in Mid-Continent Region
6. J. F. ROBERTS, Jurassic *Ostracoda*
7. E. M. RICE, Notes on Gober Chalk
8. L. F. MCCOLLUM, A. C. ELLISOR, and JOHN TEAGLE, Correlation of Pecan Gap Chalk Group in Texas
9. J. HARLAN JOHNSON, Coprolite Horizon in Pennsylvanian of Chaffee and Park Counties, Colorado
10. J. HARLAN JOHNSON, Algae of Genus *Ottonosia* from Pennsylvanian of Central Colorado
11. WILLARD F. BAILEY, Study of Micropaleontology and Stratigraphy of Lower Pennsylvanian of Central Missouri
12. GAYLE SCOTT, A Cretaceous Ammonite with an Anomalous Suture Pattern
13. MARGARET FULLER BOOS, Heavy Minerals of Some Front Range Granites

IV. GEOPHYSICS

1. E. E. ROSAIRE, Gulf Coast Exploration Trends
2. W. T. BORN and J. E. OWEN, Velocity of Elastic Waves in Amherst Sandstone
3. SYLVAIN PIRSON, The Effect of Anisotropy on the Apparent Resistivity Curves
4. O. F. SUNDT, Recent Developments in Gravitational Prospecting
5. J. C. KARCHER and EUGENE MCDERMOTT, Practical Limitations of Resistivity Methods
6. W. P. JENNY, Geological Correlation of Gravimetric and Magnetic Anomalies of the Gulf Coast (by title)

Presidential Address: The New Challenge

Frank Rinker Clark

In opening this, the nineteenth annual meeting of The American Association of Petroleum Geologists, in the midst of new ideas and changing concepts, it seems appropriate to consider the present sphere and future usefulness of the geologist and the engineer, to the society which they serve. In the past, scientists have concerned themselves merely with their own scientific work. In the future, they must interest themselves also in social problems. As an indication of what others may think of the usefulness of science, I quote excerpts from an address by Henry A. Wallace,[1] Secretary of Agriculture, delivered before the Boston meeting of the American Association for the Advancement of Science, December 29, 1933:

> Even today, I suspect that more than half of the engineers and scientists feel that the good old days will soon be back when a respectable engineer or scientist can be an orthodox stand-patter without having the slightest qualm of conscience. It is so nice to feel that there are great supermen from whom, directly or indirectly, you draw your own sustenance, who, sitting Jove-like above us lesser mortals, make possible the free functioning of the law of supply and demand in such a way that their profits enlarge at the same rate that our research expands. . . .
>
> The scientists and inventors have an intense kind of religion of their own—certain standards to which they like to be true—and as long as they could get enough money to pursue their researches, why should they care how some one else handled the social and economic power derived from these researches? . . .
>
> Yet science, all this time, has been creating another world and another civilization that simply must be motivated by some conscious social purpose, if civilization is to endure. Science and engineering will destroy themselves and the civilization of which they are a part unless there is built up a consciousness which is as real and definite in meeting social problems as the engineer displays when he builds his bridge. The economist and the sociologist have not yet created this definite reality in their approach; can you, trained in engineering and science, help in giving this thought a definite body?

The Association is but 19 years old and during this brief time we have grown in numbers and in importance in our own field. The geologist and the engineer have worked their way into, and have become an integral part of, the petroleum industry on the theory that the oil resources of the world could be explored and exploited more efficiently and more economically by the aid of science. In the beginning the oil fraternity obviously were skeptical and threw out this challenge: find and produce more oil at less expense.

Geologists and engineers, in both exploration and exploitation, together with the wildcatter, have so far met this challenge, but in performing a short-sighted, though phenomenal achievement of producing a veritable flood of oil, we have not been concerned sufficiently with the effect of a vast over-supply of petroleum on the great industry and the society which we serve.

The major fuel industries, coal and petroleum, have been seriously crippled by over-production and over-expansion.

The coal industry was almost wrecked even before our present depression, to which all existing evils are attributed, because there were more mines and more man-power than consumptive demand could support.

Over-production and over-expansion have threatened the very existence of the oil industry, and wanton selfishness and a disregard for the rights of others have induced governmental regulation.

[1] Henry A. Wallace, "The Social Advantages and Disadvantages of the Engineering-Scientific Approach to Civilization," *Science* (January 5, 1934).

In the producing branch there is the offset obligation maintained to protect the rights of adjoining property. This law is right and just if it is not abused.

But in the marketing branch offset filling stations are built and operated for an entirely different motive, the net result being to so split the consumptive demand that many stations operate at a loss. Statistics indicate that during the past few years the consumption of petroleum products was only slightly below the highest peak and yet this branch of the industry, through over-expansion and illegal cut-throat practices, remained "in the red." Is there any sanity in such conduct of business? The remedy seems to be cooperation, fairness and a reasonable plan of operation and distribution.

The present individualism and industrialism, without too great a stretch of the imagination, may be likened in some respects to many genera of invetebrates in past geologic history. These lowly creatures were completely annihilated through their own efforts in excessive and burdensome ornamentation. Such a catastrophe to the human race may seem, to many, inconceivable, but are we sure that, without taking proper cognizance of our changing conditions and state of mind, we may escape extinction?

The new challenge to geologists and engineers is much broader than the discovery and production of oil. In the future we must concern ourselves not only with the problem of supplying petroleum products to society, at reasonable prices, but we must exert our influence and training to the end that the supply does not greatly exceed the consumptive demand. This problem lends itself admirably to scientific solution. It should not be necessary to invoke legal means to curtail the flush production and to reduce waste of any oil well or any oil pool. A knowledge of the scientific problems involved, plus honesty and coöperation among the interested operators is all that is necessary in carrying out a well balanced plan of development and production designed to give each interested party the recoverable oil that originally was contained in the reservoir beneath his leasehold estate without irreparable damage to the adjoining property. For example, the most efficiently operated and developed oil fields today, under restricted production, in which equality of rights is recognized, are those in which the plan of development and operation is formulated and carried out in the light of scientific knowledge, and by voluntary agreement among the operators and by their mutual honesty and coöperation.

Another important matter that indicates a wide departure from previous standards, and one that requires sane thinking, is the growing tendency, of individuals, states and nations, to cancel obligations entered into in good faith. It is hard to conceive of anything more demoralizing to society in general, and more particularly to those intimately affected. The debtor must lose all sense of obligation and equity, and the creditor must lose his property and faith in his fellowmen. Even the suggestion of such practices stifles business, to say nothing of the psychological effect on society. Lack of honesty and fair play, and a disregard for contractual obligations are extant and thinking people must throw the bulwark of their judgment and influence against them.

I should like to remind you that it may be more important at times to consider the *misuse* of scientific data than it is to consider their proper use.

Geologists, engineers, and physicists have engaged intensively in the field of fundamental research pertaining to the occurrence and production of oil and have achieved satisfactory success, yet they have merely begun. Fundamental research must be fostered and promoted because we are in dire need of more factual information. The object of this discussion here is to point out some of the pitfalls ahead if due care is not used in the proper use and *not misuse* of the results of research. We have no apprehension concerning the use of the results by those conducting the research, but what about the misuse of this information by so-called technical experts, unscrupulous lawyers, and operators, and governmental regulatory bodies who do not know the proper applications and limitations of such information?

The general use of rotary drilling resulted in crooked holes that distorted geologic information and complicated producing problems. Engineers immediately devised instruments and technique to measure the amount and direction of the deflection of the hole from the vertical. Not only can the drill hole be measured after it has been drilled, but it is possible to so control the drilling as to reach any desired location for the bottom of the hole. This technique has been misused for the express purpose of drilling across property boundaries and securing oil and gas which rightfully belong to others. A sad state of affairs comparable to the "high-jacker" who "holds up" his fellow men and takes property not his own.

Scientific data frequently are misapplied in giving expert testimony. In an effort to successfully justify curtailment of flush production, so-called expert testimony has been given under oath. Much of this testimony has been contradictory and has been given and accepted as fact when in reality it is hardly sound theory.

Some lawyers win or lose lawsuits on slight technicalities of the law or in the language of legal documents, but scientists who are concerned only with truth and facts, should not be parties to misleading statements.

A common weakness of a few of our engineers seems to be in trying to reduce geological conditions in oil and gas reservoirs to mathematical exactness. They talk of the movement and behavior of fluids in subsurface reservoirs as though they knew all of the many and varying factors which materially affect such behavior. They are prone to accept theoretical deductions as fact and draw conclusions which are not yet justified. We need more thinking and less talking.

Other petroleum engineers now talk about evaluating the sources of energy in any given oil reservoir whether such indeterminate energy be free gas, dissolved gas, oil, or salt water. In certain pools each or all of these sources of energy may be effective in recovering the oil, but we lack sufficient information to assign to each such source of energy, or any other, its proper relative value in the amount of work it performs in the recovery of the oil. For example, we do not know the exact amount of oil, gas, or salt water originally contained in any given portion of the reservoir. We also talk about water drive and the energy it exerts in recovering the oil, but in many pools there is no water drive and little or no effective energy is derived from the water in expelling the oil and gas. Suppose we assign water energy to properties wholly outside the oil pool and in the water zone, how far from the oil-water contact does such energy exert an influence? Should the property at the outcrop of the

reservoir formation, the whole area overlying the reservoir, or the property adjacent to the oil-water contact receive credit for this so-called energy that can not be measured? It seems obvious that we must clear our muddy thinking and consider carefully the practical applications of such indeterminate factors before we advocate any such drastic theories wherein we assign the relative and respective values to the sources of energy that drive the oil out of the reservoir into the drill hole. We need more facts and less theory.

We, as an Association, are opposed to dabbling in politics. My interpretation of this attitude, in which I am honestly in accord, is in its application to the practice of "lobbying." We, as an scientific organization, have no business trying to secure special privileges through the medium of the Lobby. This whole process is intended to serve selfish ends and therefore is out of the realm of scientific thought or tolerance.

We, as individuals, do have a very definite duty to society in the field of politics. The type of man in politics today, as well as in the past, obviously is the man whom the majority of those who actually vote, desire in office. It does not necessarily follow, however, that this type of man is that desired by those who are eligible to vote and fail to exercise this privilege. We are all familiar with the political demagog and the dishonest men who are elected to public office and thus entrusted with the public's money and its welfare and we shall continue to have this type so long as there is an ignorant and indiscriminating electorate to which the politician can appeal.

It does little or no good to try to reform, or even to punish, the professional wrong-doing politician after he has been elected to office. The time for thought and action is before our public servants are elected. Scientists have literally created a new world in the last century and now must assist in adapting the social sciences to their discoveries and inventions. It is inescapable that every citizen owes a part of his time to society.

In the days long past, when unlimited frontiers existed, nations, states, groups, and individuals were self-sufficient and they could live and enjoy personal liberty without any aid or interference from the balance of society. These conditions appear to be gone forever. Whether we care to admit it or not, we are at the dawn of a new day. The success of future civilization depends upon coöperative effort and a full realization of the rights of others in all words and deeds.

In this brief discussion I have mentioned only a few malpractices and only a few neglected duties of the scientist; there are many more. The new challenge commands the scientist to recognize the change in social problems created by his own discoveries and inventions. He must concern himself with the practical application of scientific data to present and future society and must advocate and practice coöperation with due regards for the rights of others. He must also awaken to his added political responsibility and help shape the future destinies of civilization.

MINUTES, NINETEENTH ANNUAL BUSINESS MEETING BAKER HOTEL, DALLAS, TEXAS, MARCH 22–24, 1934

FRANK R. CLARK, *presiding*

The meeting was called to order at 4:50 P.M., March 22, 1934, by president Frank R. Clark. William B. Heroy acted as secretary.

1. *Election of honorary members.*—President Clark announced the election by the executive committee to honorary membership in the Association of Marius R. Campbell, Charles Schuchert, and Joseph A. Taff.

2. *Nominations of officers.*—The president called for nominations of officers of the Association for the year 1934–1935 and the following nominations were made.

For president,	WILLIAM B. HEROY, nominated by Max W. Ball
For vice-president,	E. F. DAVIS, nominated by Frank A. Morgan
	EDWIN B. HOPKINS, nominated by E. L. DeGolyer
For secretary-treasurer,	M. G. CHENEY, nominated by Ira H. Cram
For editor,	L. C. SNIDER, nominated by Donald C. Barton

3. *Ballot committee.*—The president appointed the following to serve as the ballot committee: Raymond F. Baker, L. Murray Neumann, E. Russell Lloyd.

4. *Qualifications for voting.*—It was moved, seconded, and carried that members who have paid any part of their current dues and are otherwise qualified under the Constitution shall be permitted to vote at the present meeting of the Association.

5. *Resolutions committee.*—The president appointed the following resolutions committee: W. E. Wrather, Earl B. Noble, J. Harlan Johnson.

The meeting adjourned at 5:15 P.M. until March 24, 1934, at 9:00 A.M.

The adjourned meeting was called to order at 9:25 A.M., March 24, 1934, by president Frank R. Clark.

6. *Reading of minutes.*—It was moved, seconded, and carried that the reading of the minutes of the annual meeting held at Houston, Texas, March 23–25, 1933, be dispensed with, inasmuch as they had been published in the *Bulletin*.

7. *Reports of officers.*—The reports of president Frank R. Clark, secretary-treasurer William B. Heroy, and editor L. C. Snider were read (Exhibits I, II, III).

8. *Report of ballot committee.*—The ballot committee reported the election of the following officers: president, William B. Heroy; vice-president, Edwin B. Hopkins; secretary-treasurer, Monroe G. Cheney; editor, L. C. Snider. The report of the ballot committee is attached as Exhibit IV.

9. *Report of general business committee.*—The report of the general business committee (Exhibit V) was made by the chairman, Russell S. Knappen. The recommendations contained therein were on motion adopted. The reports of the committee on geologic names and correlations, M. G. Cheney, chairman; of the research committee, Donald C. Barton, chairman; of the committee on applications of geology, F. H. Lahee, chairman; of the representative of the Association on the Division of Geology and Geography, National Research Council, Russell S. Knappen, are attached to these minutes as Exhibits VI–IX, inclusive.

10. *Report of resolutions committee.*—The report of the resolutions committee (Exhibit X) was unanimously adopted.

11. *Introduction of new officers.*—Retiring president Frank R. Clark introduced to the meeting the incoming officers: president, William B. Heroy; vice-president, Edwin B. Hopkins; secretary-treasurer, Monroe G. Cheney; and editor, L. C. Snider.

The nineteenth annual business meeting adjourned at 10:15 A.M.

WILLIAM B. HEROY, *secretary* FRANK R. CLARK, *president*

EXHIBIT I. REPORT OF PRESIDENT.

(Association Affairs, March, 1933–March, 1934)

In reviewing the most important Association matters during the past year, I shall be brief, leaving the details of our finances to Heroy, our editorial work to Snider, and various committee reports to the various chairmen of these committees.

I wish to express my gratitude and appreciation for the high honor bestowed upon me. I have had the hearty coöperation of the executive committee, the district representatives, fellow members, and the headquarters staff, in the administration of Association affairs. In some quarters apprehension was expressed because our executive committee were widely scattered, but no serious handicap was apparent. Two or more members were able to meet frequently and six formal committee meetings were held: one in Houston; three in Dallas; one in New York, and one in Washington, D.C.

Membership.—One of the most vital and perplexing problems during the past year was the delinquent member who was in distress through lack of employment. The district representatives were instructed, at the 1933 business meeting, to make a personal canvass of members in arrears, to ascertain whether or not the Association could help them. This survey indicated that a great many members were not on company payrolls and that many unemployed geologists were financially embarrassed. Local groups, during the year, made organized efforts to find employment for their members, and a clearing house was maintained at Tulsa headquarters, although this medium was not very effective, due to a lack of proper contacts with employers. The records at headquarters, through changes in address, did indicate that a substantial number of geologists returned to employment during the last 9 months of 1933. The success of this survey can not be measured alone by the number of members who received employment, but the Association was repaid for the time spent because of these personal contacts with members which helped to weld the organization together.

Conditions in the industry showed definite improvement in mid-summer and business has continued on the up-grade to the present time. These conditions were reflected in the rate at which geologists were returned to employment, which enabled many of our delinquent members to pay dues.

The total number of delinquents, from a total of 1,461 on March 1, 1933, was gradually reduced during the year as follows: May 31—956; August 31—825; November 30—752; December 31—719. The total loss in membership for the year ending March 1, 1933, was 222, and the loss for the year ending

March 1, 1934, was 293. The total members in arrears, March 1, 1933, was 1,461 and on March 1, 1934, was 1,052.

On December 31, 1933, 411 members and associates on the roster were in arrears 2 years and these, under our By-Laws, would be dropped from the Association. These members received a special notice calling attention to the delinquency and the provisions in the By-Laws, and extending the time of payment from January 1 to February 15, 1934. I am gratified to report that 100 of these 411 members were able to pay delinquent dues and most of them paid the full 2 years' dues. We are also pleased at the rate members are paying the current year's dues.

Necrology.—I am sorry to report the loss by death of ten of our members. This loss is one for which there is no compensation.

Finances.—As previously stated, I shall leave to Heroy the report on the details of the Association's finances; however, I want to say that he has diligently scrutinized costs and supervised expenditures with the utmost care. The net results are that even with a 20 per cent reduction in dues, and other losses in revenue, we published more pages of the *Bulletin* than the previous year and ended the year with a slight surplus.

Special publications.—The volume, *Geology of California*, by Ralph Reed, is a real contribution to the science and to the Association. We owe a debt of gratitude to Reed for this volume. This book was published in June, 1933, and by the end of the year 958 copies of the 1,500 that were printed, had been sold. The book is now paid out and the profits go into the revolving publication fund.

Problems of Petroleum Geology, under the co-editorship of W. E. Wrather and F. H. Lahee, was originally designated Volume III, following Volumes I and II, *Structure of Typical American Oil Fields*. After the manuscripts were assembled, it was found that the original name was not indicative of the contents of the volume and the executive committee changed the name to *Problems of Petroleum Geology*, with a subtitle, "A Sequel to Structure of Typical American Oil Fields."

This volume, containing approximately 1,000 pages, has been dedicated as a memorial to Sidney Powers because he was largely instrumental in soliciting the papers and because he spent much time on the editorial work of various papers. The book is being financed by the general fund and the profits, after the cost has been returned to that fund, will go into the Sidney Powers Memorial publication fund. It is hoped that this volume may be ready for distribution in June or July of this year. We have advance orders now (March, 1934) for 844 copies of this volume.

Geology of Natural Gas, under the editorship of Henry Ley, is still in manuscript form but should be ready soon for routine editing. It is hoped that this volume will be published this year.

New geologic data in the Gulf Coast, together with the fact that many Gulf Coast fields are not described in the original Salt Dome volume, created the demand for a companion volume on Coastal Domes to include as many as possible of the fields that have not already appeared in Association publications. Type is being held of *Bulletin* papers dealing with additional Gulf Coast fields and also additional papers have been solicited by George Sawtelle. These papers are now coming in and we hope that this volume may be published early next year.

Sidney Powers Memorial publication fund.—Because of Sidney Powers' untiring efforts in helping to develop and to perfect the publications of the Association, together with the many articles published by himself, and the encouragement he gave toward helping others to write, it was deemed fitting to create a Memorial Publication Fund to his memory. No concerted effort has been made to increase the size of this as yet small fund and I therefore urge all those who can, to contribute in order that this fund may be sufficient for the publication of special volumes.

Finance committee.—At the annual business meeting, 2 years ago, it was voted to create a finance committee, consisting of 3 members to be appointed by the president. The purpose of this committee is to advise with the executive committee on all important questions concerning the finances of the Association. The 3 members on this committee are Joseph E. Pogue (re-appointed in 1933 for a period of 3 years); E. DeGolyer, and W. E. Wrather.

Committee on geologic names and correlations, M. G. Cheney, chairman.—The committee on geologic names and correlations was created for the purpose of helping authors and members in problems of nomenclature. One of the main objects of this committee is to coöperate with authors, field workers, the United States Geological Survey, the Geological Society of America, the State Geological Surveys, and other publishers of geologic literature, to avoid duplication in geologic names and to pass upon the merit of new names that may be submitted in publications of the Association.

Research committee, Donald C. Barton, chairman.—During the past year the research committee has actively fostered discussion of problems of research. Its special activities were: (1) an interesting and extended discussion of the "Origin and Evolution of Oil" at Houston preceding the Association's eighteenth annual meeting; (2) a mid-year meeting at Dallas preceding the Petroleum Section meeting of the A.I.M.E. This meeting was well attended and the subject was "Oil and Gas Reservoir Formations"; (3) the formation of local research groups, as a result of which two such groups have been formed, one at Houston with Willis Storm, chairman, to study the age of uplift of the Gulf Coast salt domes; the other in Kansas with R. C. Moore, chairman, to continue the detailed stratigraphic study of the Pennsylvanian and the Permian.

A round table discussion was held preceding the nineteenth annual meeting in Dallas. The subject under discussion was "Time of Migration of Petroleum with Special Reference to the Age of Petroliferous Structures and to Levorsen's 'Studies in Paleogeology.'"

Committee on applications of geology, F. H. Lahee, chairman.—The committee on applications of geology was active during the past year and covered a broad field of activities. The work of this committee embraced teaching of geology at High Schools and night school classes, exhibitions at State Fairs, talks before civic clubs, the establishment of local permanent museums, and discussions on the importance of better geological understanding of the problems in connection with the proration of oil and gas.

I wish to compliment Dr. Carey Croneis and other members of the Association, who planned and supervised the petroleum geological exhibit at "A Century of Progress." It gave in graphic form a comprehensive picture of petroleum geology in its relation to the exploration and exploitation of oil.

Sixteenth International Geological Congress.—The Sixteenth International

Geological Congress was one of the outstanding events in which the Association participated during the past year. Our Association contributed the sum of $1,000.00 to help defray the preliminary expenses and organization of this Congress, which was held in Washington, July, 1933.

Preceding and following the technical meetings in Washington, extensive field trips were made to various parts of the United States. One of these, personally conducted by W. E. Wrather, included a visit to many of the important oil fields of the Mid-Continent and Gulf Coast. Delegates from 7 foreign countries, together with several local members of the Association, were present on the whole trip. I wish to compliment Wrather on the success of this field trip and also to express our appreciation to the several local groups for their planning and execution of details. The whole trip moved with clocklike precision.

The following members of the Association were appointed as special representatives to the Sixteenth International Geological Congress: E. DeGolyer, Frank W. DeWolf, Alexander Deussen, James H. Gardner, K. C. Heald, O. B. Hopkins, Ralph W. Reed, L. C. Snider, Hugh D. Miser, and David White. All of these except Gardner and Deussen attended the Congress.

Twenty-one members of the Association were on the official program for papers, covering subjects of general geologic interest, particularly petroleum. Those appearing on the program were: Hans Stille, R. J. Holden, Alfred C. Lane, Stanislav Zuber, I. M. Goubkin, A. I. Levorsen, Frank R. Clark, Wallace E. Pratt, John M. Muir, Parker D. Trask, Edwin T. Hodge, Teiichi Kobayashi, Raymond C. Moore, David White, Charles Schuchert, Donald C. Barton, Eliot Blackwelder, W. H. Emmons, W. S. Behre, Robert H. Dott, and Hugh D. Miser.

Approximately 175 A.A.P.G. members were registered at the Congress and it is estimated that between 75 and 100 attended the sessions at Washington.

Further details regarding this Congress, and the Association's participation therein, will be found in *Bulletin* No. 9, Volume 17, pages 1139–1145, by Robert H. Dott.

Presidential trips.—The wide distribution of the members handicaps the solidarity of the Association. In order to compensate for this wide distribution, the executive committee chooses the convention city in various districts so that every member, sooner or later, may attend the annual meetings. Districts were long ago created in which members are elected to represent local groups at annual business meetings. Even with these provisions we need additional contacts to stimulate the interest of local groups in the Association.

In recent years the executive committee have made it a point, whenever possible, to visit districts and discuss Association affairs with the local members. This custom was followed during the past year and members of the executive committee have been able to meet with many local societies. The president spent considerable time and money during the past year in visiting local groups and in attending geologic meetings in the interest of the Association. Following the annual meeting in Houston, he visited the San Antonio, San Angelo, and Fort Worth societies, and in each place received considerable constructive criticism regarding Association policies. Later, Shawnee, Oklahoma, and Wichita, Kansas, were visited and at Wichita the president read a paper on "The Origin and Accumulation of Oil."

In July, 1933, the president joined Wrather's field trip A-6, of the Sixteenth International Geological Congress, and proceeded with his party to Washington, D.C. This trip afforded an opportunity to meet with the local societies at Oklahoma City, Fort Worth, Tyler, and Houston. At the technical sessions in Washington, the president represented the Association as one of the honorary vice-presidents of the committee on organization of this Congress.

The next trip of the president, in the interest of the Association, was to attend the Petroleum Section of the A.I.M.E. meeting, and the meeting of our research committee, in Dallas in October. After these meetings, the president and the editor, L. C. Snider, went to Shreveport and met the local group at luncheon followed by a round table discussion of Association affairs. We next met the Houston Society at a luncheon and had an opportunity to discuss with local members important matters. This trip was extended to include San Antonio, San Angelo, and Fort Worth again.

The president received a cordial invitation to attend the annual meeting of the San Antonio section at Corpus Christi and regrets that he was unable to be present because of the conflict with the meeting of the A.P.I. in Chicago the same week.

The next trip in the interest of the Association was made to attend the annual meeting of the Pacific Coast section at Los Angeles. This meeting was well attended and an exceedingly interesting program was presented. The president was given a place on the technical program and read a paper on "The Origin and Accumulation of Oil." The warm welcome and genuine hospitality were appreciated. After the meeting in Los Angeles, he went to San Francisco and met with the local group at a luncheon where important matters of the Association were discussed.

From San Francisco he went to Denver and attended a special dinner and meeting with the local group. He presented his paper on "The Origin and Accumulation of Oil" and also discussed Association matters.

The president attended the meeting of the Geological Society of America in Chicago, Christmas week. Important matters were discussed with the secretary-treasurer, W. B. Heroy, and many other members who also attended this meeting.

I recommend and urge that the officers, whenever possible, visit the local groups and discuss with members the affairs of the Association.

FRANK R. CLARK, *President*

EXHIBIT II. REPORT OF SECRETARY-TREASURER

(Year Ending March 24, 1934)

MEMBERSHIP

It is the sad duty of the secretary to record the names of those members of the Association who have been separated from us by death: Harry Mayo Andreen, James E. Hoover, E. N. Lowe, A. F. Melcher, Alan Reiff, John R. Roberts, Eric A. Starke, J. Lauer Stauft, Irving M. Streeter, and Ira A. Williams.

The Association has met the full force of the serious loss of membership which seemed inevitable at the beginning of 1933. As a result, total membership as of March 1, 1934, has been reduced to 2,043, a net loss over the year

of 293 members and associates. The total loss has been even greater, amounting to 354 members and associates, 8 through death, 7 through withdrawal, and 339 dropped for non-payment of dues. Offsetting this there has been a small increase due to the election of new members.

As of March 1, 1934, 332 members and associates are in arrears as to dues for 1933, and 1,052 members and associates have not paid their dues for 1934. However, 991 members are in good standing this year as compared with 875 last year, which we may take as an encouraging indication.

In the accompanying tables (I, II, and III) details of the status and distribution of the membership are fully set forth.

FINANCES

GENERAL

In entering the fiscal year 1933 it was evident that caution must be exercised in conducting the finances of the Association if its activities and its service to the membership were to be unimpaired. A serious loss of membership and a corresponding reduction in income from dues was clearly foreseen and it was realized that expenses must be correspondingly reduced if a healthy financial condition was to be maintained. A budget was adopted which was thought to be sufficiently conservative even for the critical situation which the Association faced. While in some respects the estimates made have fallen short of realization the year has, on the whole, been financially successful and the Association is in a stronger financial position today than a year ago.

Receipts from dues have closely approximated the budget estimate, but there has been a substantial falling off in revenue from subscriptions to the *Bulletin*. Salaries had already been reduced drastically in 1932 and any further economies of importance in the Association office seemed to be obtainable only at the price of impairment of service. A new contract for the printing of the *Bulletin* has reduced greatly the cost of publication and has made possible the reduction in expenditures required to balance the budget. The anticipated saving of $8,000 in this item has been fully realized, the actual result being a reduction in printing cost of $8,167.31.

The savings made have been fully passed on to the membership in the form of reduced dues. The result of the year's operations has been that the Association has broken about even with reference to the General Fund and has added a profit of over $3,000 to the Publication Fund.

We face the year 1934 with a further reduction in membership and with decreased revenue from dues in prospect. It is probable that as a result of the steps being taken by the National Government the costs of publication may be somewhat increased during the year because of higher wages and prices of materials. An anticipated increase in the cost of paper has been met by purchasing a supply sufficient to issue the *Bulletin* during 1934. It is possible that these factors may require some reduction in the size of the *Bulletin*. With the exercise of reasonable prudence, however, the Association should be able to carry through the year 1934 without any serious impairment of activities because of lack of finances.

AUDIT

As required by the Constitution an audit of the books of the Association for the fiscal year ended December 31, 1933, has been made and the report

of the Auditors has been published in the March, 1934, issue of the *Bulletin*. The figures contained in the report have been used as a basis for the comparisons and analyses which follow. The figures given, except where otherwise stated, are on an accrual basis.

FINANCIAL TRANSACTIONS

Income.—Following the practice of last year the income derived from the publications of the Association has been segregated from that obtained from other sources. In the report for 1932, $8.00 of the dues of each member and associate was set aside to represent the cost of the subscription to the *Bulletin*. Because of the reduction in the annual dues this amount has been decreased to $6.00 in preparing the 1933 statements. The amount so set aside was $10,332.00 and this amount together with other receipts from publications make a total of $22,908.57, which may be considered the gross income of the Association from publications.

The remainder of the receipts from dues, amounting to $9,292.00, was allocated to meet the general expenses of the Association. Other receipts bring the total of general revenues to $11,721.65.

Table IV shows the various sources of income and compares the amounts derived during the last four years. Total income from all sources in 1933 was only 83.5 per cent of that for 1932 and 49.9 per cent of that for the peak year, 1930. In 1933, 56.7 per cent of the income was derived from dues, 17.4 per cent from advertising and subscriptions to the *Bulletin*, 18.9 per cent from the sale of publications, and 6.3 per cent from investments.

Expenses.—In keeping with the reduced income the expenditures of the Association were again drastically reduced. The total for the year was $29,793.79. The expenses in 1932 were $35,491.54, so that the decrease amounts to $5,697.75, or 16.5 per cent. The expenses have been segregated into Administrative and Publication expense. The total Administrative expense was $10,795.38 in 1933, in comparison with $11,094.11 in 1932, while the total Publication expense was $18,998.41 in 1933 in comparison with $24,397.43 in 1932. Of the total expenditures, 36.3 per cent were for administration and 63.7 per cent for publication.

Salaries of the staff were not changed during the year. The most important reduction in expense was in the cost of printing the *Bulletin*, which was $7,773.95 in comparison with $14,718.84 in 1932, a reduction of $6,994.89. Other minor reductions in manufacturing costs total $1,172.42 so that the total reduction in the expense of manufacturing the *Bulletin* was $8,167.31. Table V itemizes the Expenses of the Association and makes comparisons for the last 4 years.

Net income.—Gross Income of the Association for 1933 was $34,630.22. Expenses were $29,793.79 leaving Net Income before Depreciation and Reserves of $4,836.43. Depreciation of Inventory was set up amounting to $1,900.00. A Reserve of $167.50 was created to take care of contributions to the Sidney Powers Memorial Fund. Securities appreciated $707.65. Considering these items the Association had a Net Accrued Income of $3,476.58.

Depreciation.—The market value of the Association's investments was somewhat greater at the end of 1933 than of 1932. This increase, $707.65, has been credited against the reserve previously established to take care of the decline in value which occurred in 1931. The policy previously established

with regard to the depreciation of the value of publications carried in stock for sale was continued and a further allowance of $1,900.00 was made for this purpose. Publications in stock at the end of the year which cost the Association $36,791.74 were carried at a value of $15,259.70. Inventory at the end of the year comprised 23,868 paper-bound copies of the *Bulletin*, 2,001 bound sets of the *Bulletin* and 1,525 books.

Table VI summarizes the income and expense of the Association and shows the allowance made for depreciation for the last four years. These items are reconciled with the Net Income as shown by each year's Balance Sheet.

Cost of Bulletin.—The cost of manufacturing the *Bulletin* in 1933, including printing, engraving, separates, and binding, was $9,707.07. Expenses of editing, mailing, etc. bring the total to $16,286.86 as shown by the report of the Auditors. To this cost there has been added a proportion of the clerical salaries, making the total cost of the *Bulletin* $16,974.87. This last figure has been used in Table VII, which compares the cost of the *Bulletin* for the past four years.

The average monthly edition in 1933 was 2,589 as compared with 3,145 the previous year, a reduction chiefly due to loss of membership. The total pages of text was 1,568, 190 pages more than in 1932 and lacking but 44 pages of the maximum year, 1929. The high standards of paper and printing set in the past have been fully maintained.

Although the size of the *Bulletin* was increased over last year, both the total and the unit costs of manufacturing have been greatly reduced because of the more favorable printing contract. The total cost for 1933 is $9,033.30 less than for 1932. The actual expense of printing and binding in 1933 was less than half that in 1932. The cost per copy printed was reduced from 64 to 55 cents while the cost per page printed was reduced from $14.83 to $9.22.

BALANCE SHEET

Assets.—At the close of 1933 the Total Assets of the Association were $70,374.32, an increase over 1932 of $6,407.48. The principal items are cash, investments and inventory.

Cash.—The cash on deposit at the end of 1933 totaled $11,108.78, an increase from the first of the year of $705.10. The increasingly strong cash position of the Association is indicated by the following figures showing cash on hand at the end of each year:

Dec. 31, 1930	$8,579.77
Dec. 31, 1931	8,205.82
Dec. 31, 1932	10,403.68
Dec. 31, 1933	11,108.78

Of the cash on hand at the end of 1933, $7,658.30 was prepaid revenue for 1934, so that the cash belonging to Surplus was $3,450.48. This large prepaid revenue is chiefly due to the payment by many of the members of $15.00 dues in 1933, of which $3.00 was carried forward as 1934 revenue when the amount of the dues was reduced to $12.00 at the last annual meeting.

Investments.—The cost of all investments at the end of 1933 was $51,-949.38, an increase of $7,612.47 over the previous year. The market value as determined by the Auditors was $37,624.38 as compared with $30,598.46 at the close of 1932, an increase of $7,025.92. During the year $5,000.00 of U. S.

Liberty 4¼% Gold Bonds, 1947, and $3,000.00 of Dominion of Canada 4½% Gold Bonds, 1936, were purchased. Comparative figures concerning the investments of the Association are presented in Table VIII.

Surplus.—The Surplus at the end of 1933 was increased by the addition of a Net Profit of $3,476.58. It should be noted, however, that this increase in surplus was made up of profits to the Publication Fund of $3,581.92 and to the Research Fund of $334.28 while the General Fund sustained a loss of $439.62. This loss to the General Fund was due, however, to depreciation of securities amounting to $496.10, so that the operating profit of the General Fund was $56.48. The profit earned by the Publication Fund was largely due to the splendid sales of the *Geology of California*, published for the account of the Publication Fund during the year.

SPECIAL FUNDS

The Association now has four special funds. The ordinary business, including the publication of the *Bulletin*, is conducted by the use of the General Fund. Receipts from dues and from the *Bulletin* are allocated to it. At the close of the year it totaled $51,474.80.

Payments received from life members are segregated in the Life Membership Fund, the income of which is placed in the General Fund.

The Research Fund includes gifts made to the Association for research in petroleum geology. The income from this fund during the past year has been added to the principal.

The Sidney Powers Memorial Fund, instituted last year, has received certain contributions which are now carried as a special reserve.

The Publication Fund has been used to finance the special publications of the Association. During the past year the *Geology of California* was financed from this fund. The success of this publication has increased the amount of the fund from $14,237.16 at the end of 1932 to $17,819.08 at the end of 1933.

The status of the Publication and Research Funds is shown in Tables IX and X.

Special publications.—Table XI summarizes information relative to the special publications of the Association. Contracts were executed during 1933 for the printing of two additional volumes: *Problems of Petroleum Geology*, to be financed by the General Fund, and *Geology of Natural Gas*, by the Publication Fund. Type on the first volume is now being set and the second will be ready for the printer in the near future.

The pre-publication price of *Problems of Petroleum Geology* has been fixed at $5.00 by the executive committee.

BUDGET

The probable receipts and expenditures for the fiscal year 1934 have been estimated and a budget has been prepared. Total revenues have been estimated at $39,315.00 and expenditures at $38,887.00. Leaving out of consideration items relating to the publication of special volumes the revenues are estimated at $27,315.00 and the expenses at $24,662.00.

The treasurer has received from the executive committee the fullest cooperation, and the favorable result of the year's operations must be attributed in large measure to their support. The treasurer wishes to express thanks to the members of the finance committee for valued coöperation. The loyal sup-

port of the entire membership of the Association in this period of financial stress is deeply appreciated. The business manager and headquarters staff have contributed in large measure to the success of the financial program and have carried increasing administrative work in the best of spirit.

W. B. HEROY, *secretary-treasurer*

TABLE I

TOTAL MEMBERSHIP BY YEARS

May 19, 1917	94	March 20, 1926	1,504
February 15, 1918	176	March 1, 1927	1,670
March 15, 1919	210	March 1, 1928	1,952
March 18, 1920	392	March 1, 1929	2,126
March 15, 1921	621	March 1, 1930	2,292
March 8, 1922	767	March 1, 1931	2,562
March 20, 1923	901	March 1, 1932	2,558
March 20, 1924	1,080	March 1, 1933	2,336
March 21, 1925	1,253	March 1, 1934	2,043

TABLE II

COMPARATIVE DATA OF MEMBERSHIP

	March 1, 1933		*March 1, 1934*	
Number of honorary members	6		6	
Number of life members	2		2	
Number of members	1,800		1,634	
Number of associates	528		401	
Total number members and associates		2,336		2,043
Increase in membership		—		—
Decrease in membership		222		293
Applicants elected, dues unpaid	2		5	
Applicants approved for publication	13		11	
Recent applications	6		18	
Total applications on hand		21		34
Applications approved for transfer, dues unpaid	19		6	
Applications for transfer approved for publication	2		1	
Recent applications for transfer on hand	2		4	
Total applications for transfer on hand		22		11
Number of members and associates withdrawn	30		7	
Number of members and associates dropped	228		339	
Number of members died	8		8	
Total loss in membership		266		354
Number of members and associates in arrears, previous year	481		332	
Members in arrears, current year	1,061		813	
Associates in arrears, current year	400		239	
Total number members and associates in arrears, current year		1,461		1,052
Total number members and associates in good standing		875		991

TABLE III

Geographic Distribution of Members

March 1, 1934

Arizona....2	Louisiana....62	Ohio....9
Arkansas....9	Maryland....3	Oklahoma....366
California....244	Massachusetts....13	Oregon....2
Colorado....45	Michigan....13	Pennsylvania....50
Connecticut....4	Minnesota....7	S. Dakota....2
Delaware....1	Mississippi....8	Tennessee....1
Dist. of Columbia....26	Missouri....30	Texas....610
Florida....6	Montana....9	Virginia....2
Idaho....1	Nebraska....13	Washington....5
Illinois....26	Nevada....1	W. Virginia....17
Indiana....4	New Jersey....6	Wisconsin....3
Iowa....9	New Mexico....15	Wyoming....11
Kansas....79	New York....75	
Kentucky....10	N. Carolina....1	

Total Members in the United States....1,800

Angola, Africa....2	D. East Indies....13	Palestine....1
Argentina....16	Egypt....1	Persia....8
Australia....2	England....13	Peru....3
Austria....3	France....8	Poland....2
Belgian Congo....1	Germany....13	Roumania....4
Brazil....2	Holland....18	Russia....3
B. West Indies....9	India....1	Scotland....3
Canada....19	Italy....2	Spain....1
China....1	Japan....5	Sweden....1
Colombia....10	Madagascar....2	Switzerland....5
Cuba....3	Mexico....24	Turkey....3
Czechoslovakia....1	New Zealand....1	Venezuela....39

Total members—Foreign....243

Grand total....2,043

TABLE IV

COMPARISON OF ACCRUED INCOME BY YEARS

Items	*1930*	*1931*	*1932*	*1933*
Dues—Members	$26,217.50	$28,952.50	$23,580.00	$17,124.00
Associates	7,520.00	6,730.00	3,918.00	2,500.00
Life	—	—	—	—
Totals	33,737.50	35,682.50	27,498.00	19,624.00
Bulletin—Subscriptions	4,205.32	3,998.90	3,471.10	3,339.13
Advertising (Net)	6,735.05	4,780.90	2,945.61	2,689.55
Totals	10,940.37	8,779.80	6,416.71	6,028.68
Back Numbers, etc.				
Bound Volumes	4,704.50	2,648.83	2,275.88	1,711.70
Back Numbers	1,178.45	873.84	590.57	485.02
Indexes	101.80	62.72	42.60	36.60
Alberta Symposium	—	313.67	79.02	22.80
Geophysics Symposium	—	169.08	177.58	—
Totals	5,984.75	4,068.14	3,165.65	2,256.12
Special Publications				
Continental Drift	404.00*	318.30*	153.36*	159.85*
Structure Vol. I	2,279.19*	902.65*	291.74*	260.26*
Structure Vol. II	6,562.51*	(680.37*) (476.01)	368.31	315.93
Geology of California	—	—	28.00*	3,555.73*
Totals	9,245.70	2,377.33	841.41	4,291.77
Other Income				
Convention Receipts	1,550.00	2,132.53*	1,282.73*	9.96
Donations	5,365.00*	1,325.00*	—	167.50‡
	260.00†	500.00†	—	
Interest and Profit on Investments	1,915.30	1,807.87	1,567.90	1,512.87
	226.80*	584.80*	588.74*	634.27*
	33.56†	57.57†	58.67†	61.78†
Miscellaneous	115.65	126.68	17.90	43.27
	23.74*	11.76*	—	—
Total Income	$69,398.37	$57,453.98	$41,437.71	$34,630.22

* Income of Publication Fund.
† Income of Research Fund.
‡ Income of Sidney Powers Memorial Fund.

TABLE V

COMPARISON OF ACCRUED EXPENSES BY YEARS

Items	*1930*	*1931*	*1932*	*1933*
General and Administrative Expense				
Salaries—Manager	$ 3,750.00	$ 3,416.67	$ 2,176.23	$ 1,929.19
Clerical	6,212.61	5,430.00	4,658.13	4,717.67
Rent	93.00	300.00	300.00	300.00
Postage	1,210.58	1,001.57	479.33	941.37
Telephone & Telegraph	325.28	235.94	197.73	255.99
Freight and Express	—	10.08	6.96	5.65
Office Supplies & Exp.	2,250.69	343.64	197.68	220.68
Printing & Stationery		846.79	461.55	365.04
Insurance and Taxes	246.75	238.49	180.12	124.77
Audit Expense	521.58	373.41	150.00	350.00
Legal Expense		154.74	—	—
Custodian Fee	—	38.14	20.72	—
Constitution Expense	—	—	212.49	—
Association Seal	—	—	24.00	—
Exchange and Refunds	66.42	57.36	10.55	22.18
Executive Expense	68.89	16.30	—	—
Travel Expense	124.16	58.64	—	192.53
Convention Expense	1,878.89	21.61	8.51	22.15
Donation, Soc. Econ. Pal. and Min.	1,000.00	454.00	368.00	348.00
Donation Internatl. Geol. Cong.	—	500.00	500.00	—
Donation Natl. Res. Coun.	50.00	—	—	—
Research Program	—	9.78	—	—
Misc. Expenses	61.28	—	5.00	5.23
Depreciation, Furn. & Fix.	289.55	323.56	329.43	329.43
Bad Debts, Gen. Fund	—	3,238.00	807.68	665.50
Loss on Investments, Gen. Fund	108.75	—	—	—
Pub. Fund	170.00	—	—	—
Total, Gen. and Admin.	18,428.43	17,068.72	11,094.11	10,795.38
Publication Expense				
Salaries—Manager	3,750.00	3,416.68	2,176.22	2,545.24
Editorial	3,998.04	4,054.52	3,441.63	3,533.60
Printing Bulletin	21,267.76	19,425.74	14,718.84	7,773.95
Engravings	2,006.10	1,561.60	1,017.05	1,195.05
Separates	593.93	613.41	247.32	198.05
Stencils and Mailing	481.66	749.06	233.11	133.72
Binding Bulletins	1,632.60	1,629.00	1,608.06	406.30
Postage	299.15	(†)	574.16	533.05
Freight and Express	—	—	48.48	—
Moving Expense	—	—	120.58	—
Copyright Fees	—	—	22.52	24.00
Discounts	—	—	81.48	49.99
Purchase Back Nos.	—	140.75	20.00	17.50
Advertising Books	—	33.60	—	—
Bad Debts	—	—	87.98	15.05
Miscellaneous	87.51	32.82	—	1.85
Special Publications	9,822.60	511.33	—	2,571.06
Total Pub. Expense	$43,939.35	$32,168.51	$24,397.43	$18,998.41
Total Expense	$62,367.78	$49,237.23	$35,491.54	$29,793.79

† Included in General Expenses.

TABLE VI

COMPARISON OF NET INCOME BY YEARS

Items	*1930*	*1931*	*1932*	*1933*
Accrued Income	$69,398.37	$57,453.98	$41,437.71	$34,630.22
1931 Income accrued in 1930	450.00	—	—	—
	69,848.37	57,453.98	41,437.71	34,630.22
Expenses				
General and Administrative	18,428.43	17,068.72	11,094.11	10,795.38
Publication	43,939.35	32,168.51	24,397.43	18,998.41
Total	62,367.78	49,237.23	35,491.54	29,793.79
Net Income before Depreciation and Reserves	7,480.59	8,216.75	5,946.17	4,836.43
Reserve for Depreciation of Investments	—	—	938.00	−707.65
Depreciation of Inventory	−4,127.92	380.23	3,581.12	1,900.00
Reserve for Sidney Powers Memorial Fund	—	—	—	−167.50
Net Accrued Income after Depreciation as per Balance Sheet	11,608.51	7,836.52	1,427.05	3,476.58
Depreciation of Investments charged to Surplus	—	13,413.75	—	—
Dues written off and charged to Surplus	708.19	665.00	—	—
Net Accured Income after all Depreciation	$10,900.32	$−6,242.23	$1,427.05	$3,476.58

TABLE VII

COMPARISON OF COST OF BULLETIN

	1930	*1931*	*1932*	*1933*
Total expenses	$34,967.67	$33,129.01	$25,008.17	$16,974.87
Monthly edition	4,000	4,250–	3,700–	2,918–
		4,100	3,000	2,412
Total copies printed	48,000	49,350	38,947	31,068
Total pages printed, including covers	2,016	1,820	1,686	1,842
Total pages of text	1,610	1,476	1,378	1,568
Total cost per copy	0.73	0.67	0.64	0.55
Total cost per page for total printed	0.0043	0.0044	0.0050	0.0038
Total cost per page, including covers	17.34	18.20	14.83	9.22
Cost of printing only	21,267.76	19,425.74	14,718.84	7,773.95
Cost of printing per copy	0.4430	0.3936	0.3779	0.2502
Cost of printing per inside page	10.81	10.96	8.98	4.33
Cost of printing per page printed, less covers	0.0028	0.0027	0.0029	0.0017

TABLE VIII

INVESTMENTS

1932 Values	*Cost*	*Market Value End of Year*	*Depreciation*	*Per Cent Depreciation*
General Fund	$26,873.43	$18,205.98	$ 8,667.45	32.2
Life Membership Fund	613.30	579.55	33.75	5.5
Publication Fund	16,195.44	11,112.39	5,083.05	31.4
Research Fund	1,268.04	700.54	567.50	44.7
Totals	44,950.21	30,598.46	14,351.75	31.9
1933 Values				
General Fund	35,040.70	25,868.40	9,172.30	26.2
Life Membership Fund	629.44	604.44	25.00	3.9
Publication Fund	14,246.61	10,094.81	4,151.80	29.1
Research Fund	1,351.73	1,056.73	295.00	21.8
Totals	51,268.48	37,624.38	13,644.10	26.6

TABLE IX

PUBLICATION FUND

Income		
Sale of Special Publications	$3,975.84	
Interest	634.27	
Increase of Inventory	752.11	
Appreciation of Securities	931.25	$6,293.47
Expenditures		
Discount on Publications	30.35	
Geology of California	2,664.30	
Bad Debts	15.05	
Miscellaneous	1.85	2,711.55
Net Profit to Surplus		3,581.92
Surplus represented by		
Cash	5,221.32	
Investments	10,094.81	
Accounts Receivable	219.20	
Inventory	1,838.71	
Accrued Interest Receivable	95.20	
Prepaid Charges, Geology of Natural Gas	349.84	$17,819.08

TABLE X

RESEARCH FUND

Income	
Interest on Investments	$61.78
Appreciation of Securities	272.50
	334.28
Expenditures	—
Profit to Surplus	334.28
Surplus represented by Accrued Interest Receivable	23.71
Investments	1,056.73
Total Surplus	1,080.44

TABLE XI

SPECIAL PUBLICATIONS

	Continental Drift	*Structure Vol. I*	*Structure Vol. II*	*Geology of California*	*Total*
Inventory, Dec. 31, 1932	$ 76.83	$1,009.77	$2,646.00	—	$3,732.60
Inventory, Dec. 31, 1933	—	875.91	2,451.60	$ 962.80	4,290.31
Sales, 1933	159.85	260.26	315.93	3,555.73	4,291.77
Cost of Sales	76.83	133.86	194.40	1,701.50	2,106.59
Gross Profit	83.02	126.40	121.53	1,854.23	2,185.18
Total Edition	1,500	2,500	2,500	1,500	
Copies on Hand, Dec. 31, 1932	39	347	735	—	
Copies on Hand, Dec. 31, 1933	—	301	681	542	
Number of Pages	240	510	780	355	
Cost (Inventory)	$ 1.97	$ 2.91	$ 3.60	$ 1.78	
Selling Price When Issued	3.50	4.00	4.00	4.00	
Present Selling Price					
Members and Associates	—	5.00	5.00	5.00	
Non-Members	—	7.00	7.00	5.00	

TABLE XII

BUDGET, 1934

	General Fund	Publication Fund	Total
REVENUES			
Operating Revenues:			
Publications:			
Bulletin:			
Subscriptions	$ 3,300.00	—	$ 3,300.00
Advertising	2,700.00	—	2,700.00
Total	6,000.00		6,000.00
Bound Volumes	1,500.00	—	1,500.00
Back Numbers	450.00	—	450.00
Index	30.00	—	30.00
Alberta Symposium	15.00	—	15.00
Total Bulletin, all items	7,995.00		7,995.00
Special Publications:			
Structure Volume II	250.00	—	250.00
Geology of California	—	1,000.00	1,000.00
Problems of Petroleum Geology	6,000.00	—	6,000.00
Geology of Natural Gas	—	5,000.00	5,000.00
Dues:			
Members, 1,250, at $12.00, $15,000.00			
Assoc. 250, at $8.00, $2,000.00	17,000.00	—	17,000.00
Miscellaneous:			
Convention Receipts	—	—	—
Total Operating Revenues	31,245.00	6,000.00	37,245.00
Non-Operating Revenues:			
Interest on Investments	1,520.00	550.00	2,070.00
Interest on Bank Account	—	—	—
Total Revenues	$32,765.00	$6,550.00	$39,315.00
EXPENSES			
General and Administrative	10,442.00	20.00	10,462.00
Publications:			
Bulletin	14,200.00	—	14,200.00
Problems of Petroleum Geology	6,725.00	—	6,725.00
Geology of Natural Gas	—	7,500.00	7,500.00
Total Expense	$31,367.00	$ 7,520.00	$38,887.00
Surplus or (Deficit)	1,398.00	(970.00)	428.00

Note. If $6.00 of the dues of each member is for purposes of accounting considered as applicable to the *Bulletin* the revenues of the *Bulletin* will total $16,995 and the expenses $14,200, leaving a *Bulletin* profit of $2,795.

EXHIBIT III. REPORT OF EDITOR

The *Bulletin* for the year 1933 contained 1794 pages, exclusive of advertising, an increase of 164 pages over 1932, and only about 100 pages less than the maximum issue for any year of the history of the Association. The number of pages devoted to both major and minor articles showed an increase over the previous year, while the space devoted to Association affairs decreased slightly.

During the early part of the year the papers on hand for publication were sufficient only to keep the monthly issues to the regular size and a real shortage

of material for the December *Bulletin* was narrowly avoided. At about this time, however, the *Bulletin* was fortunate in securing a considerable number of papers from three unexpected sources. First, we were given the opportunity of publishing the papers on petroleum geology delivered at the International Geological Congress at Washington, several of which were contributed by members of the Association. Second, it was decided to somewhat restrict the size of *Problems of Petroleum Geology* formerly known as Volume III of the symposium on *Structure of Typical American Oil Fields*, and which had outgrown the original plans, and to publish in the *Bulletin* a few papers intended for this volume. Third, a similar change in the plans for *Geology of Natural Gas* restricted this volume to papers on the gas fields of North America and made available for the *Bulletin* several interesting and valuable contributions on foreign gas fields. Naturally, the substitution of publication in the *Bulletin* for publication in the volumes for which the papers were originally intended has been made only with the consent and coöperation of the authors, which is deeply appreciated.

With this influx of papers, the *Bulletin* staff can prepare tentative schedules for the issues for a longer period than has been the case at any time in the history of the Association. Nevertheless, the need of contributions from the members is still with us and a comparatively few months will again bring back more nearly normal conditions of actual need of manuscripts if the *Bulletin* is to be kept at its present size and unless the rate of contribution by members increases. For the next few months, it will be necessary for authors to bear themselves with some patience in awaiting publication of their articles. Particularly, some papers of a general and scientific nature, whose value will not be lessened by a short postponement of publication, may have to yield place temporarily to such papers as those describing active fields which must necessarily have early publication to be of the maximum value.

The general editorial policy outlined in the report of Ralph D. Reed, editor for the previous year, has been continued. As a rule the editorial policy is to regard the paper as belonging to the authors and not to the editors and to keep the editorial revision to a minimum. At the same time, it is felt to be not only a privilege but a duty to insist on certain well recognized standards of English usage and to suggest such changes as will in the editors' best judgment improve the papers in form or content.

For one department the *Bulletin* staff must depend largely on the individual members. The personal notes in "At Home and Abroad" are, in the present editor's opinion at least, an extremely important means of keeping the members in touch with each other's doings and we should have many more of them. For these notes, the Editorial staff asks the coöperation of the members in sending to the editors or the business manager, notes concerning themselves or other members with whom they are acquainted.

In regard to the special volumes: Dr. Reed's *Geology of California* has been a most gratifying success from all standpoints. The announcement of the appearance of *Problems of Petroleum Geology*, under the editorship of W. E. Wrather and F. H. Lahee, has been made in the March *Bulletin*. The volume, *Geology of Natural Gas*, under the editorship of Henry A. Ley, will go to the printers within the next few months. At present, a volume is being planned which will supplement the old Salt-Dome volume by bringing up to date the advances in knowledge of salt domes, with inclusion of description of salt domes discovered since the publication of the original volume. Several papers

have already been secured for this volume, under the leadership of George Sawtelle. The volume should be ready for publication during the early part of 1935 if present plans are carried out, but these plans are still too indefinite to give more than the foregoing tentative and generalized outline of the scope of the volume.

L. C. SNIDER, *editor*

EXHIBIT IV. REPORT OF BALLOT COMMITTEE

For president,	WILLIAM B. HEROY	Unanimous
For vice-president,	EDWIN B. HOPKINS	92
	E. F. DAVIS	49
For secretary-treasurer,	M. G. CHENEY	Unanimous
For editor,	L. C. SNIDER	Unanimous

RAYMOND F. BAKER L. MURRAY NEUMANN E. RUSSELL LLOYD

EXHIBIT V. REPORT (MINUTES) OF GENERAL BUSINESS COMMITTEE

The meeting was called to order at the Baker Hotel, Dallas, Texas, 2:00 P.M., March 21, 1934, by Russell S. Knappen, chairman. W. B. Heroy acted as secretary.

The following members were present:

Chairman, Russell S. Knappen; *vice-chairman,* Ed. W. Owen
Executive Committee: Frank R. Clark, F. H. Lahee, George Sawtelle, W. B. Heroy, L. C. Snider
Members-at-Large: Max W. Ball, Hugh D. Miser, K. C. Heald, R. D. Reed represented by Earl B. Noble
Division of Paleontology: Gayle Scott
Division of Geophysics: Not represented
District Representatives:
Amarillo, J. D. Thompson
Appalachian, H. E. Crum represented by John L. Rich
Canada, not represented
Capital, A. A. Baker represented by H. D. Miser
Dallas, L. W. Orynski
East Oklahoma, A. L. Beekly, R. T. Lyons
Fort Worth, H. B. Fuqua
Great Lakes, C. L. Dake
Houston, Paul Weaver
Mexico, not represented
New Mexico, Edgar Kraus
New York, J. T. Duce represented by R. F. Baker
Pacific Coast, W. A. English represented by Clark Gester, Roy G. Mead represented by Frank A. Morgan, C. B. Osborne represented by Earl B. Noble
Rocky Mountain, C. E. Dobbin
San Antonio, J. M. Dawson
Shreveport, M. W. Grimm represented by C. L. Moody
South America, not represented
Southern Permian Basin, J. F. Hosterman

Tyler, not represented
West Oklahoma, R. W. Laughlin
Wichita, E. A. Wyman
Wichita Falls, not represented

1. *Minutes of previous meeting.*—It was moved, seconded, and carried that the reading of the minutes of the last meeting of the committee be omitted, as the minutes had been published in the *Bulletin.*

2. *Reading of reports of committees.*—It was moved, seconded, and carried that the following reports be read to the committee: (a) report of the committee on geologic names and correlations; (b) report of the research committee; (c) report of the committee on applications of geology; (d) report of the representative of the Association on the Division of Geology and Geography, National Research Council.

3. *Report of committee on geologic names and correlations.*—After reading of the report it was moved, seconded, and carried that the report be accepted, and referred to the general business meeting with the recommendation that it be not read but that it be published in the May, 1934, *Bulletin.*

4. *Report of research committee.*—After reading of the report it was moved, seconded, and carried that the report be accepted, and referred to the general business meeting with the recommendation that it be not read but that it be published in the May, 1934, *Bulletin.*

5. *Report of committee on applications of geology.*—After reading of the report it was moved, seconded, and carried that the report be accepted, and referred to the general business meeting with the recommendation that it be not read but that it be published in the May, 1934, *Bulletin.*

6. *Report of representative of Association on Division of Geology and Geography, National Research Council.*—After reading of the report it was moved, seconded, and carried that the report be accepted, and referred to the general business meeting with the recommendation that it be not read but that it be published in the May, 1934, *Bulletin.*

7. *Contribution to Society of Economic Paleontologists and Mineralogists.*—It was moved, seconded, and carried that the general business committee recommends the adoption of the following resolution:

Resolved, that a contribution of $2.00 per member be paid by the Association to the Society of Economic Paleontologists and Mineralogists for each member of the Society who is also a member of the Association and who pays dues for the year 1934.

8. *Program of research committee.*—D. C. Barton reported that the research committee plans to hold a mid-year meeting at the International Petroleum Exposition at Tulsa, May 12–19, the subject of the meeting to be "The Recovery of Petroleum." The research committee voted to extend an invitation to the research committee of the A.P.I., to the Oklahoma City Geological Society, the Tulsa Geological Society, and the Stratigraphic Society of Tulsa. The research committee also recommended that an appropriation, not exceeding $100.00, be made from the Research Fund for circularizing the Association membership in connection with F. B. Plummer's project for a census of research studies under way by members of the Association. It was moved, seconded, and carried that the program of the research committee be approved.

9. *Program of committee on geologic names and correlations.*—M. G. Cheney recommended to the business committee that a special committee be appointed to compile a glossary of structural terms used in petroleum geology. It was moved, seconded, and carried that the recommendation be referred back to the committee on geologic names and correlations for further consideration and report to the executive committee, and that it was the sense of the meeting that such a work is desirable.

10. *Public Works funds.*—It was moved, seconded, and carried that the committee recommends that the executive committee, on behalf of the Association, petition the Federal Administrator of Public Works for the allocation of a substantial amount of Public Works funds to the United States Geological Survey for geologic work in the United States and immediately take all necessary and proper steps to carry out the purpose of this resolution.

11. *Annotated Bibliography of Economic Geology.*—It was moved, seconded and carried that K. C. Heald present to the general business meeting the situation of the *Annotated Bibliography of Economic Geology* and urge the support of the membership.

12. Frank A. Morgan discussed the importance of better representation of oil companies at the annual meeting. It was agreed that about March 1 the president of the Association should write the executives of the larger oil companies, inviting their attention to the importance of sending their geologists to the annual meeting, and indicating the leading papers on the program which discuss the areas in which the particular companies are interested.

The meeting of the general business committee adjourned at 5:15 P.M.

RUSSELL S. KNAPPEN, *chairman* WILLIAM B. HEROY, *secretary*

EXHIBIT VI. REPORT OF GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

There seem to have been no outstanding achievements made by this committee during the past year. However, the various members of the committee have assisted the editors of the *Bulletin* in the editing of certain papers, and have no doubt contributed in many other ways to the clarification of problems of nomenclature and correlation in their respective areas. The only meetings of this committee since its last report were held at the 1933 meeting of the Association at Houston. A majority of the committee and several interested members of the Association were present, both at the scheduled meeting on March 21, and at the subsequent meeting on March 24. There was general agreement that the activities and methods of procedure outlined in the first annual report of this committee (this *Bulletin*, Vol. 17, pp. 603–4) should be continued.

Dr. Henry V. Howe, of Louisiana State University, brought before the committee the question of using the name "Sabine" instead of "Wilcox," as discussed in his paper presented at the general meeting. The committee recommended that Dr. Howe's paper be published in the *Bulletin* with a note stating that the question would be referred to the committee on stratigraphy of the National Research Council, with decision to be published later. Dr. Howe expressed his desire to follow such decision as that committee might make. This article was published in the June, 1933, issue of the *Bulletin*, with note appended. Discussion of this paper by Alexander Deussen, a member of this committee, was included in the July issue of the *Bulletin*. The secre-

tary has been advised that the national committee referred to above will doubtless express its opinion on this question during 1934.

The action ot the Houston Geological Society in appointing a committee to investigate current usage and recommend names for certain formations in the Gulf Coast area is to be highly commended. The geologic note entitled "Coastal Plains Stratigraphic Nomenclature," in the December, 1933, *Bulletin*, gives the results of this important work.

The committee has had under consideration the preparation of a glossary dealing with structural terms used in petroleum geology. The sentiment seems to be favorable, and this subject will be further discussed at the coming meeting in Dallas.

It is expected that publication by this Association (July, 1933) and by the Geological Society of America of the "Classification and Nomenclature of Rock Units" will prove particularly helpful to our members in preparing reports and contributions for the *Bulletin*.

This committee hopes to render useful service to the Association during the coming year by stimulating work on current questions of geologic names and correlation; also, to render such aid to the editorial staff as may be requested.

M. G. CHENEY, *chairman*

EXHIBIT VII. REPORT OF RESEARCH COMMITTEE

The special activities of the research committee during the past year have been three: (1) a mid-year open meeting, (2) the formation of local research groups, and (3) a dinner and round-table discussion on the evening preceding the annual meeting.

1. The mid-year meeting was held at Dallas, Texas, in October, the day before the meeting of the Petroleum Section, A.I.M.E. The key subject of the meeting was "Oil and Gas Reservoir Formations." The key speakers and their subjects were:

W. R. Berger and R. H. Fash, "Permian Limestone Reservoirs of West Texas,

F. C. Edson, "Siliceous Lime and Sand Reservoirs in Oklahoma and Kansas,"

E. Russell Lloyd, "Permian Limestone Reservoirs,"

L. F. McCollum, "The Edwards Limestone Reservoirs,"

T. F. Petty, "Acid Treatment of Lime Reservoirs,"

P. G. Russell, "Reservoirs of the Bend Limestones, North-Central Texas,"

R. B. Whitehead, "Study of Cores of Sandstone Reservoirs, Greta Field, Texas, in Relation to Selecting Proper Casing Points and Securing Efficient Gas-Oil Ratio."

Written contributions and discussions were submitted by:

James I. Daniels, "Porosity of Certain Limestone and Dolomite Reservoirs in Oklahoma and Kansas,"

W. V. Howard, "Porosity in Limestone Reservoirs,"

H. S. McQueen, "Porosity in Cambro-Ordovician Limestones and Dolomites of Missouri,"

W. H. Twenhofel, "Comments Regarding Possibility of Primary Porosity in Limestones,"

Paul D. Torrey, "The Oil Sands of Pennsylvania."

C. V. Millikan, E. A. Stephenson, and J. B. Umpleby discussed the problem of the geological information which should be had by petroleum engineers. The discussion was lively.

2. Local research groups were the subject of considerable discussion in the meeting of the research committee last March. In conformity with the general sentiments expressed by the members of the committee at the meeting, a circular letter in regard to the formation of such local research groups was sent to all district representatives, and to members of the committee.

Two local research groups have been formed.

At Houston, a research group of five members was formed under the chairmanship of Willis Storm to study the age of uplift of the Gulf Coast salt domes. That study is preliminary to the study of the age of accumulation of the oil on the Gulf Coast domes. According to oral report, a good beginning has been made on the problem.

In Kansas, a research group of six has been formed under the general chairmanship of R. C. Moore to continue the detail stratigraphic study of the Pennsylvanian and Permian, with reference to conditions of sedimentation, classification, et cetera. A grant of $3,000.00 was obtained from The Geological Society of America for the work on the Pennsylvanian, which should be completed during 1934.

3. A lively and extended round-table discussion of "The Origin and Evolution of Oil" was held on Wednesday evening preceding the opening of the general meeting at Houston last March.

A similar dinner and round-table discussion are scheduled for the coming meeting at Dallas. The keynote of the discussion is to be "Time of Migration of Petroleum with Especial Reference to the Age of Petroliferous Structures and to Levorsen's Studies in Paleogeology."

A special meeting of the research committee is being planned at the Petroleum Exposition and Congress at Tulsa, Oklahoma, this coming May 12 to 19. The details of the plan for the meeting will be completed at the March meeting of the committee.

The chairman and Professor Plummer have had considerable discussion in regard to making a survey of the research that is actually being done by members of the A.A.P.G. We had hoped to make a preliminary survey in time to report to the committee this March, but have not had time to do so.

A major duty of the members, themselves, of the research committee always is the contribution of research. In reply to my questionnaire in regard to their activities as members of the committee, the following information has been received.

1. F. B. Plummer has carried on and directed a great deal of research during the past year and will report at Dallas to the committee on part of it.

2. L. C. Uren reports that in coöperation with several oil companies, the University of California has carried on a program of research on the relative permeabilities of California oil reservoir rocks. The Schlumberger electrical coring method is being studied, more especially with the intent to discover whether the Schlumberger "porosity" profile actually is a measure of the porosity or of some other property of the reservoir rock. Another project under study is the variation of the pressure gradient within the reservoir rock about a high-pressure well.

3. C. E. Dobbin reports that a large part of his spare time was occupied

serving on a committee of the Rocky Mountain Association of Petroleum Geologists which solicited funds from the Public Works Administration to be expended largely on necessary geologic research problems under the supervision of the U. S. Geological Survey.

4. R. C. Moore, with a research group composed of Frank C. Greene, Robert H. Dott, G. E. Condra, C. W. Tomlinson, and H. D. Miser, obtained a grant of $3,000.00 from The Geological Society of America for continuation of a detailed study of the stratigraphy of the Permian with reference to conditions of sedimentation, classification, et cetera. They are endeavoring to complete the study this year.

5. Parker D. Trask has been spending his whole time on his work on source beds and has nearly completed the manuscript of a paper "Preliminary Study of Source Beds in the Mesozoic Rocks on the West Side of the Sacramento Valley, California."

6. F. H. Lahee (with W. E. Wrather and others) has spent much time in the completion of the rather laborious work of editing *Problems of Petroleum Geology* (formerly called Vol. III of the symposium *Structure of Typical American Oil Fields*), one of the most important research committee projects. He also assisted Henry A. Ley on the volume, *Geology of Natural Gas*, another important research committee project.

7. L. C. Snider reports that he has done nothing on the committee, but it is known by the chairman that in line of company duty he has been doing an interesting piece of research in surveying possibilities for the future discovery of bonanza oil fields in the United States.

8. M. G. Cheney has been working on the geology of well spacing.

9. D. C. Barton has carried forward his study of the variation of crude oil. His early studies found a normal variation of increase of percentage of light constituents with depth and age. The present study is finding that there is a parallel variation of the gravity of each fraction with depth and age.

Two of the important projects of the research committee, (1) the third volume of the symposium, *Structure of Typical American Oil Fields*, now entitled *Problems of Petroleum Geology*, and (2) the volume *Geology of Natural Gas*, are practically completed. The former volume is in press. All but one or two papers of the latter volume have been received.

DONALD C. BARTON, *chairman*

EXHIBIT VIII. REPORT OF COMMITTEE ON APPLICATIONS OF GEOLOGY

The committee on applications of geology[2] has fifteen members who are located in most of the larger centers of the activities of this Association. In several of these centers our committeemen have organized subcommittees to assist in promoting our aims. Thus, in an efficient manner, we are able to reach a great many of the public in our efforts to inculcate the meaning and practical value of geology.

I am glad to report that much has been accomplished in certain districts. In others, due to reduction in the number of our resident members and more pressing duties of those remaining, less has been done. In summarizing our

[2] When first organized in 1932, this was designated the committee on public relations; but by vote of the Association, March 25, 1933, its name was changed to committee on applications of geology. (See *Bulletin*, Vol. 17 (1933), pp. 577 and 597).

results during the year just passed, I shall dwell on our accomplishments only where decided progress seems to have been made.

From California Professor Soper reports that last year an evening class in geology was conducted in one of the high schools in Los Angeles, and with such success that this year similar classes were held in five high schools. About 200 students attended, most of these being beyond the usual high school age. The courses, which are free, include instruction in oil geology as well as in other branches of economic geology. Members of Dr. Soper's subcommittee, of which he is chairman, are Harry R. Johnson, Earl B. Noble, O. P. Jenkins, and G. Dallas Hanna. Arrangements for a geological exhibit are being made.

A. E. Brainerd states that, in their efforts to further certain important projects under the U. S. Geological Survey, members of the Rocky Mountain Association of Petroleum Geologists have been active in discussing and explaining the practical importance of geology before various organizations in Denver and in other parts of the Rocky Mountain District.

Marvin Lee, serving with the Kansas State Corporation Commission, has helped to emphasize the desirability of geologic information in connection with oil proration programs. In his resumé of work accomplished he refers to the topographic model of Kansas on display at the Capitol, to the state geologic map now under construction, and to the utilization of geological advice in connection with impounding of lakes, study of coal and zinc resources, and investigations of other natural resources.

Carey Croneis and other members of our Association devoted a great deal of time and thought to preparation of the wonderful Petroleum Geology Exhibit at "A Century of Progress." An illustrated booklet of this excellent educational exhibit entitled "The Story of Oil at a Century of Progress," published under the auspices of the American Petroleum Institute, was distributed to all members of the committee. With the pamphlet was sent a description of many of the models and dioramas in the exhibit, with the hope that these might serve as patterns for construction of similar features in our local centers. At our annual convention this year in Dallas, a paper on this petroleum geology exhibit will be presented by T. A. Link, to whose ingenuity and energy many of the features of the display were due.

Wm. H. Atkinson and his subcommittee in Oklahoma have been very active in promoting the aims of our committee in their district. A course in elementary geology, formerly taught in one high school, has been introduced this year into two more high schools. The *Daily Oklahoman* has conducted a question and answer column, questions being turned over by the newspaper to the committee for reply. Furthermore, this committee has been very active in demonstrating and explaining the geological aspects of efficient oil-field development.

Quoting Hal P. Bybee, "The West Texas Geological Society, through its committee, has prepared a museum exhibit to be placed in the County Public Library, which is located in the basement of Tom Green County's most excellent court house. The exhibit consists of: (1) representative fossils from most of the fossil-bearing horizons of West Texas, (2) a collection of some fifty rocks and minerals, (3) a collection of West Texas oils, and (4) structure maps, models, et cetera, of certain West Texas oil fields. The material is all assembled and the glass case has been acquired and in a very short time the exhibit will be placed in position."

W. F. Chisholm reports that he arranged with the Shreveport Geological Society to place an educational exhibit at the Louisiana State Fair. The local committee which arranged for this exhibit included Wayne Jones, W. F. Chisholm, and A. D. Miller, chairman. On October 24 Mr. Chisholm wrote:

"Mr. W. R. Hirsch, Manager of the State Fair Association, donated a large booth 21½×10 feet in the main exhibit hall. Local merchants furnished glass show cases, et cetera. Specimens on exhibit were contributed by local geologists. They include a collection of fossils, core samples, and mineral specimens, as well as test briquettes from typical Louisiana clays. The exhibit seems to be creating considerable interest among the visitors to the fair."

Mr. Chisholm says that his committee expects to repeat this exhibit on a more comprehensive plan next year.

For the second time, in the fall of 1933, a petroleum geology exhibit was prepared for the Dallas State Fair. Our subcommittee consisted of R. B. Whitehead, J. M. Wilson, L. W. Orynski, W. E. Wrather, F. H. Lahee, and H. B. Hill, chairman. We were given a larger space than last year, 25×50 feet. Two-thirds of this we used as a space for showing the U. S. Bureau of Mines film called "Evolution of the Petroleum Industry." This we ran at 3 P.M. and 7 P.M., repeating two or three times according to the number of interested persons present. Benches were provided so that people could sit down and rest.

The other third of the booth was devoted to exhibits, including simple devices for illustrating the gravity relations of water, oil, and gas; a block diagram of the East Texas field; a collection of samples of crude oil from all parts of the U. S.; a map of Texas with the oil and gas fields illuminated from behind; a chart showing most of the simple types of oil-producing geologic structures; a series of enlarged photographs illustrating the difference between efficient and inefficient oil field practice; a group of photographs of exhibits at the Chicago "Century of Progress"; and several statistical charts.

All exhibits were prepared by individuals, or geological departments, in Dallas. Sundry expenses, amounting to nearly $275.00, were contributed by oil companies in Dallas. A geologist was hired to be present throughout most of the day each day during the continuance of the Fair. Several thousand people were sufficiently interested to spend some time in looking over the exhibit.

The geological museum planned and organized by our subcommittee in San Antonio, as mentioned in my annual report for last year[3] has become a reality. Herschel H. Cooper writes as follows:

"We are expanding our display of typical specimens of rock formations and minerals native to Southwest Texas. We are endeavoring to get a representative fossil collection from each geologic formation in Southwest Texas. We are adding a library containing current publications as well as bulletins pertaining to the geology of Southwest Texas.

"On February 26, 1934, our committee held an annual meeting at which Thornton Davis presented a review of the origin, occurrence and development of oil and gas fields in Southwest Texas during 1933. Mr. Knode of the Texas Railway Commission led a discussion on the relationship and application of geology to conservation measures of the state and federal government. The public was invited to this meeting.

[3] This *Bulletin* (May, 1933), p. 605.

"We have encouraged the preparation of articles pertaining to Southwest Texas geology. These have been published in local publications.

"A number of our members have given talks on geologic subjects, especially pertaining to the occurrence of oil and gas, et cetera, before various civic board and clubs—Real Estate Board, Canopus Club, Rotary Club, et cetera. We find a hearty response and a lively interest among the members of these organizations. I've been very gratified at the coöperation and interest manifested."

Last February a short article entitled "Some Facts Concerning the Occurrence of Oil and Natural Gas," written for use of our committee, was mimeographed as Bulletin 89 by the National Better Business Bureau of New York. I have been informed that several hundred of these bulletins have been distributed by this Bureau.

In reviewing these activities of our committee I want especially to emphasize the progress of the California subcommittee on the free courses of instruction in geology; of the San Antonio and San Angelo committees on permanent geological museums; of the Shreveport and Dallas committees, and the Missouri State Geological Survey, on geological exhibits for state fairs; and of the Wichita, Oklahoma City, and San Antonio committees on the importance of better geological understanding for purposes of proration of oil and gas. To the reader of this report the fact must be evident that our committee on applications of geology can be of increasing value both to the public in general, and to us geologists, our Association, and our profession. I feel that there is a wide field of usefulness here, and that progress is really being made.

F. H. LAHEE, *chairman*

EXHIBIT IX. REPORT OF REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY, NATIONAL RESEARCH COUNCIL

The National Research Council is organized to coördinate and assist the research studies of scientists throughout the nation. The Council consists of 7 technical divisions and 4 divisions concerned with relations between science and governments, education, and foreign countries.

The Division of Geology and Geography is one of the technical divisions. The Division consists of 9 members representing 7 geological or geographical societies and 3 members at large. The A.A.P.G. designates one member of the Division.

The work of the Division is directed by the chairman, W. H. Twenhofel, and the chairmen of 21 committees. Petroleum geologists are particularly interested in the committees on Petroleum Geology, Stratigraphy, Micropaleontology, Paleobotany, and Sedimentation. All but one of the chairmen of these committees are members of the A.A.P.G. Reports of these committees are published annually. Most of the reports are distributed free on request.

The National Research Council publishes a series of bulletins. Usually these publications survey a field and summarize existing information. Bulletins published before 1933 which particularly interest petroleum geologists include: No. 36, "Catalog of Published Bibliographies in Geology"; No. 88, "State and Federal Geological Surveys"; and No. 89, "Report of Committee on Sedimentation."

The Division of Geology and Geography has sponsored the various editions of the *Treatise on Sedimentation* and of the *Bibliography of Economic Geology*. Similarly, it assisted in publishing a color chart for description of sedimentary rocks.

In 1933, publications included Bulletin 89, "Physics of the Earth—Seismology"; Circular 106, "History of the National Research Council"; the annual report of the Division of Geology and Geography, and another volume of the *Bibliography of Economic Geology*. Complete publication lists may be obtained from the National Research Council, 2101 Constitution Avenue, Washington, D. C.

Because of economic conditions, the income and resources of the Division were sharply reduced in 1933. No research fellowships were available for geologists during the year. Appropriations were made to assist 16 research projects. Six of these projects directly concern petroleum geology, and five of the grantees are members of our Association.

Most of the grants-in-aid of research have been made to geologists connected with some educational institution. However, the grants are intended to support work by the best qualified geologist. No institutional support is necessary. Several grants were made to members of our Association who were working independently.

R. S. KNAPPEN, *representative*

EXHIBIT X. REPORT OF RESOLUTIONS COMMITTEE

Be it resolved, that we, members of The American Association of Petroleum Geologists, express our appreciation and thanks to all who have contributed to the success of the nineteenth annual meeting in Dallas, Texas, and particularly to the following.

1. To the City of Dallas and the Dallas Chamber of Commerce for their hospitable reception and courteous assistance.
2. To the Dallas Petroleum Geologists for their splendid coöperation with the officers of the Association.
3. To the wives of the local geologists for their thoughtful arrangements for the entertainment of the visiting ladies.
4. To the management of the Baker and Adolphus hotels for their courteous service and assistance.
5. To the newspapers of Dallas and to the several trade journals of the oil industry for their efficient handling of the news features of the convention.
6. To the Nieman-Marcus Company and the Dallas Little Theatre for their participation in the Ladies' Entertainment program.
7. To the local golf clubs for extending their facilities to our members and guests.
8. To the Pure Oil Company and to the management of the Grand Saline Salt Mine for permission to inspect their properties.
9. To the Ira Rinehart Service for their oil bulletins and teletype service.

Be it resolved, that these resolutions be included in the minutes of this meeting and that copies be sent to the individuals and organizations named.

EARL B. NOBLE, *chairman* W. E. WRATHER J. HARLAN JOHNSON

EXECUTIVE COMMITTEE MEETING
DALLAS, TEXAS, MARCH 20 and 24, 1934

The outgoing executive committee met at the Baker Hotel, Dallas, Texas, on March 20, preceding the nineteenth annual meeting of the Association. All members were present: F. R. Clark, F. H. Lahee, George Sawtelle, W. B. Heroy, and L. C. Snider. The committee approved applications for membership and elected to honorary membership in the Association: Marius R. Campbell of the U. S. Geological Survey, Washington, D. C.; Charles Schuchert of Yale University, New Haven, Connecticut; and Joseph A. Taff of the Associated Oil Company, San Francisco, California. It passed a resolution to provide for a second business representative for the Houston district. It recommended to the business committee for presentation to the annual business meeting of the Association (1) the usual allotment of dues to the Division of Paleontology and Mineralogy, (2) the publication of the annual reports of the committee on geologic names and correlations, the research committee, the committee on applications of geology, and the representative on the Division of Geology and Geography of the National Research Council.

On March 24, the incoming committee held a meeting with all members present: W. B. Heroy, F. R. Clark, E. B. Hopkins, M. G. Cheney, and L. C. Snider. The committee transacted routine business, authorizing the usual bonds for the officers and arranging for Association publications. The selection of the convention city for the next annual meeting was postponed till later in the year.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

William B. Heroy, *chairman*, New York, N. Y.
M. G. Cheney, *secretary*, Coleman, Texas
Frank R. Clark, Tulsa, Oklahoma
Edwin B. Hopkins, Dallas, Texas
L. C. Snider, New York, N. Y.

GENERAL BUSINESS COMMITTEE

Sam M. Aronson (1936)
Arthur A. Baker (1936)
M. G. Cheney (1935)
R. A. Birk (1936)
Frank R. Clark (1935)
H. E. Crum (1935)
C. L. Dake (1935)
E. F. Davis (1936)
Joseph A. Dawson 1935)
C. E. Dobbin (1935)
James Terry Duce (1935)
H. B. Fuqua (1935)
M. W. Grimm (1935)
S. A. Grogan (1935)
William B. Heroy (1936)
Edwin B. Hopkins (1935)
John F. Hosterman (1935)
Edgar Kraus (1935)
Roland W. Laughlin (1935)
O. C. Lester, Jr. (1935)
Theodore A. Link (1935)
R. T. Lyons (1935)
Roy G. Mead (1935)
A. F. Morris (1935)
L. Murray Neumann (1936)
Philip E. Nolan (1935)
Clarence F. Osborne (1935)
Gayle Scott (1935)
A. L. Selig (1935)
L. C. Snider (1935)
Wallace C. Thompson (1935)
Paul Weaver (1935)
Maynard P. White (1935)
E. A. Wyman (1935)

RESEARCH COMMITTEE

Donald C. Barton (1936), *chairman*, Humble Oil and Refining Company, Houston, Texas
C. E. Dobbin (1935)
A. I. Levorsen (1935)
Alex. W. McCoy (1935)
C. V. Millikan (1935)
L. C. Snider (1935)
L. C. Uren (1935)
Harold W. Hoots (1936)
R. S. Knappen (1936)
W. C. Spooner (1936)
Parker D. Trask (1936)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. S. Knappen (1934)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

Ira H. Cram, *chairman*, Pure Oil Company, Tulsa, Oklahoma
John G. Bartram
Alexander Deussen
B. F. Hake
G. D. Hanna
A. I. Levorsen
C. L. Moody
R. C. Moore
Ed. W. Owen

TRUSTEES OF REVOLVING PUBLICATION FUND

Frank R. Clark (1935)
Charles H. Row (1936)

TRUSTEES OF RESEARCH FUND

Alex. W. McCoy (1935)
Robert H. Dott (1936)

FINANCE COMMITTEE

W. E. Wrather (1935)
Joseph E. Pogue (1936)

COMMITTEE ON APPLICATIONS OF GEOLOGY

F. H. Lahee, *chairman*, Box 2880, Dallas, Texas
William H. Atkinson
Donald C. Barton
Ford Bradish
Arthur E. Brainerd
H. A. Buehler
Hal P. Bybee
Herschel H. Cooper
Carey Croneis
Marvin Lee
S. E. Slipper
E. K. Soper
Luther H. White
R. B. Whitehead

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 5 (MAY, 1934), PP. 715

Memorial

J. LAUER STAUFT

J. Lauer Stauft, field superintendent on the property of the International Petroleum Company, Limited, at Negritos, Peru, died as a result of an accident in the field on March 1. Mr. Stauft, or Pete as he was known to his friends, was born in Pittsburgh, Pennsylvania, in 1898, and graduated from the University there in 1921, receiving the degree of Mining Engineer. From February, 1922, until his untimely death he was employed by the International Petroleum Company in Peru, first, in field surveying and geological mapping, later as chief petroleum engineer, and finally in 1931 he was appointed field superintendent.

In all these lines of activity he showed real initiative and ability, but his outstanding accomplishments were in the field of petroleum engineering. His college training as an engineer, his native mechanical ability, and the zeal with which he gathered together and absorbed all available information on this subject soon placed him in the front ranks as a petroleum engineer. Not only was he outstandingly successful in this work, but he was also a great inspiration to his associates.

His early work in the production department in working over and deepening hundreds of old wells first demonstrated his mechanical ability; subsequently in the direction of gas-lift and repressuring operations he demonstrated in a most convincing way his ability to apply his technical knowledge to the solution of mechanical problems.

It is indeed unfortunate that his life's work should have been cut off at a time when he was making such contributions to his profession and before he had the opportunity of putting on record the results of his labors for the benefit of his fellow workers. His zeal for his work and his devotion to his family absorbed almost his entire time. In recent years his one hobby has been amateur broadcasting. He built himself a complete broadcasting set with which he communicated with amateur stations all over North and South America with the result that he was widely known among radio enthusiasts.

In 1927 he married Miss Flora MacDonald of Petrolia, and his wife and two children are left with his many friends to mourn his loss.

Mr. Stauft was elected to membership in The American Association of Petroleum Geologists in 1926.

OLIVER B. HOPKINS

TORONTO, CANADA
March 21, 1934

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 18, NO. 5 (MAY, 1934), PP. 716-718

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

GEORGE F. KAY, state geologist of Iowa and director of the department of geology of the University of Iowa, was an informal speaker at the regular weekly luncheon of the San Antonio Geological Society, April 16. Kay has been spending the past few weeks in San Antonio recuperating from a siege of pneumonia.

CHARLES N. GOULD, director of the former Oklahoma Geological Survey, is writing a book on Oklahoma geologists and their work. He is planning a chapter on geological societies in Oklahoma and will appreciate information on the history of such organizations. Send letters to Norman, Oklahoma.

The Cayuga oil field, recently discovered by the Tide Water-Seaboard Companies in northeastern Anderson County, East Texas, came as a result of geological work by K. A. SCHMIDT and geophysical work under the direction of H. B. PEACOCK of the Geophysical Service, Incorporated.

The Oklahoma City Geological Society, of which H. S. THOMAS, Slick-Urschel Oil Company, is president, and CLARENCE M. SALE, Magnolia Petroleum Company, is secretary, has published a series of news bulletins for its members. The first issue appeared in March and contained the new constitution and by-laws of the society. Luncheons are held at 12:15 P.M. on the first, third, and fourth Mondays; technical meetings, at 8:00 P.M. on the second Monday of each month; in the Chamber of Commerce rooms.

L. F. MCCOLLUM, past-president of the San Antonio Geological Society, was honored at a special dinner at the San Antonio Petroleum Club, April 23. McCollum has resigned his position as district geologist of the Humble Oil and Refining Company to join the geological staff of the Carter Oil Company at Tulsa, Oklahoma.

P. H. BOHART, of the Gypsy Oil Company, talked on "Operating Conditions in Mexico," and J. J. ZORICHAK, of the Stanolind Oil and Gas Company, reviewed the "Physics of High Pressures," before the Mid-Continent Section of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers, at Tulsa, April 16.

In 1933–34, for the third successive academic year, the exchange of lecturers between the departments of geology and geography at the University of Cincinnati and Northwestern University was maintained. In April JOHN L. RICH, associate professor of geology at Cincinnati, gave six lectures at Northwestern University, mainly on petroleum geology and physiography. A similar series, chiefly on ore deposits and structural control, was given at Cincinnati in March by CHARLES H. BEHRE, JR., associate professor of geology at Northwestern.

The *fiesta* of the Pacific Section of the Association was staged on April 27 and 28 at Rancho Lockharts outside of Pasadena, California. The "Gran Corrida de Toros," as set forth on a large lithographed announcement, indicated a colorful program with "BARTOTO GILLESEPPIO" as "Uno Gobernador de Fiesta."

JOSEPH H. MARKLEY, JR., geologist with The Texas Company, has been transferred from Wichita Falls to Midland, Texas.

JOHN E. VAN DALL, who has been district geologist for the Sinclair Prairie Oil and Gas Company in the Oklahoma City field since 1929, has resigned that position to become district geologist for the Magnolia Petroleum Company, with headquarters at Oklahoma City, Oklahoma.

NORMAN E. WEISBORD, formerly at 227 Haven Avenue, New York City, may now be addressed at Tartagal, Campamento Central, FCCNA, Argentina, S.A.

PAUL F. OSBORNE has changed his address from 1557 South University Boulevard, Denver, Colorado, to Box 861, Midland, Texas.

JOHN JOSEPH RUPNIK, formerly in the geological department of The Texas Company, at Houston, Texas, is now computer in the geophysical division of the same company at Los Angeles, California.

W. K. ESGEN, geologist with the Humble Oil and Refining Company, has been transferred from Houston to San Antonio, Texas, and may be addressed at 2015 Smith-Young Tower.

PAUL M. BUTTERMORE, of Fort Worth, Texas, has been connected with The Chartiers Oil Company of Pittsburgh, Pennsylvania, as geologist and Mid-Continent representative since last fall.

JOSEPH E. MORERO, who has been district geologist at Houston, Texas, for the Skelly Oil Company, has been made chief geologist with headquarters at Tulsa, Oklahoma.

GLENN D. ROBERTSON, geologist with Shell Petroleum Corporation, has been transferred from Buffalo, Texas, to Iowa, Louisiana.

H. B. FIELDS, formerly with the geophysical division of The Texas Company, Houston, Texas, has been transferred to the geological department of the same company at Wichita, Kansas.

HANS E. THALMANN has opened an office as consulting micropaleontologist at Hallerstr. 52, Berne, Switzerland, and at present is engaged in scientific research work on micropaleontological stratigraphy.

GRAYDON H. LAUGHBAUM has been appointed division geologist for the Sinclair Prairie Oil Company with headquarters at Oklahoma City, Oklahoma.

SAM GRINSFELDER, district geologist for the Union Oil Company of California, has been transferred to the company's main office at Los Angeles from the Victoria, Texas, office.

At a meeting of the Tulsa Geological Society, April 30, 1934, T. A. HENDRICKS spoke on "Stratigraphy and Sedimentation in the Arkansas-Oklahoma Coal Basin."

EVERETT C. EDWARDS has taken a position as geologist with the General Petroleum Corporation at Bakersfield, California. He received the degree of Ph.D. from the California Institute of Technology at Pasadena last June.

EDWIN MARTIN SHEPARD, of Springfield, Missouri, died, April 28, at the age of 79 years.

On December 1, 1933, DAISY WINIFRED HEATH completed 11 years as editorial secretary in the service of the Association. Miss Heath began her work on the *Bulletin* at Chicago, in December, 1922, when RAYMOND C. MOORE, of Lawrence, Kansas, was editor. The *Bulletin* was printed at the University of Chicago Press during the years from 1923 to 1927 inclusive. Since the latter part of 1927 when the *Bulletin* was first printed at Tulsa, Oklahoma, Miss Daisy and her sister, Miss Lilian, who coöperates in the editorial work, have lived in Tulsa.

On April 1, 1934, ANNA D. WHALEN completed 10 years as secretary in the Association secretary-treasurer's office and as headquarters secretary. Miss Whalen began her work for the Association at Norman, Oklahoma, in 1924, when CHARLES E. DECKER, of the University of Oklahoma, was secretary-treasurer, and has lived in Tulsa since the establishment of Association headquarters in 1926.

THEODORE CHAPIN has changed his address from Bellingham, Washington, to Johnson Hall, University of Washington, Seattle, Washington.

T. W. KOCH, formerly with the Bakersfield, California, office of the Standard Oil Company of California, has recently been transferred to the California-Arabian Standard Oil Company, in northeastern Arabia.

H. W. BELL, geologist with the Lion Refining Company, has been transferred from El Dorado, Arkansas, to Houston, Texas.

WILLIAM B. CASE has changed his address from Shell Petroleum Corporation, St. Louis, Missouri, to Shell-Union Oil Corporation, 50 West Fiftieth Street, New York City.

R. W. CLARK, formerly of 2236 Almont Street, Carrick, Pittsburgh, may now be addressed at 301 Bevington Road, Wilkinsburg, Pennsylvania.

VIRGIL E. BARNES, formerly of Galveston, Texas, is now junior topographic engineer with the United States Geological Survey. His address is 1115 Jackson Street, Amarillo, Texas.